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THE AMAZING BRAIN

Discover the science of how your brain works

WHAT MAKES YOU *YOU*?

BRAIN BOOSTERS

INSIDE THE ANIMAL MIND

FROM THE MAKERS OF BBC FOCUS MAGAZINE

THE **FOCUS** COLLECTION

THE AMAZING BRAIN

WELCOME

For centuries, we've been trying to get to grips with what makes us humans different. Is it the way we communicate? Or is it our ability to use tools to take the burden off our relatively feeble bodies? Or is it how we're able to think the unthinkable – inventing and building gadgets that transport us from the microscopic to the cosmic? Well, our 'superhuman' abilities are all down to the 1.3kg of grey matter cocooned inside our skull.

In this special issue, delve into your brain's anatomy to find out exactly how it works (p12), and discover what makes you *you* (p22). Find out how scientists are researching how to delete and implant new memories (p38). (This can't happen quickly enough in my opinion – too many naff '80s tunes clogging up my little grey cells.) On page 52, discover why power corrupts and how the brain of a dictator differs to you or I. And find out how intelligence evolved in our furry (and feathered) friends (p58), along with what goes on inside the minds of our pet pooches (p64).

This issue also looks at the serious challenges of mental health: the science of sanity (and insanity) (p70), what causes addictions (p76), the latest research into Alzheimer's disease (p82), how music can help cure many a headache (p88), and the science of what causes depression (p92).

And, finally, find out about the gadgets to make us smarter (p100) and the projects trying to create brains that run on AI (p108).

Plenty to get your little grey cells working! Enjoy!

Daniel Bennett

Daniel Bennett, Editor

FROM THE MAKERS OF BBC **FOCUS** MAGAZINE

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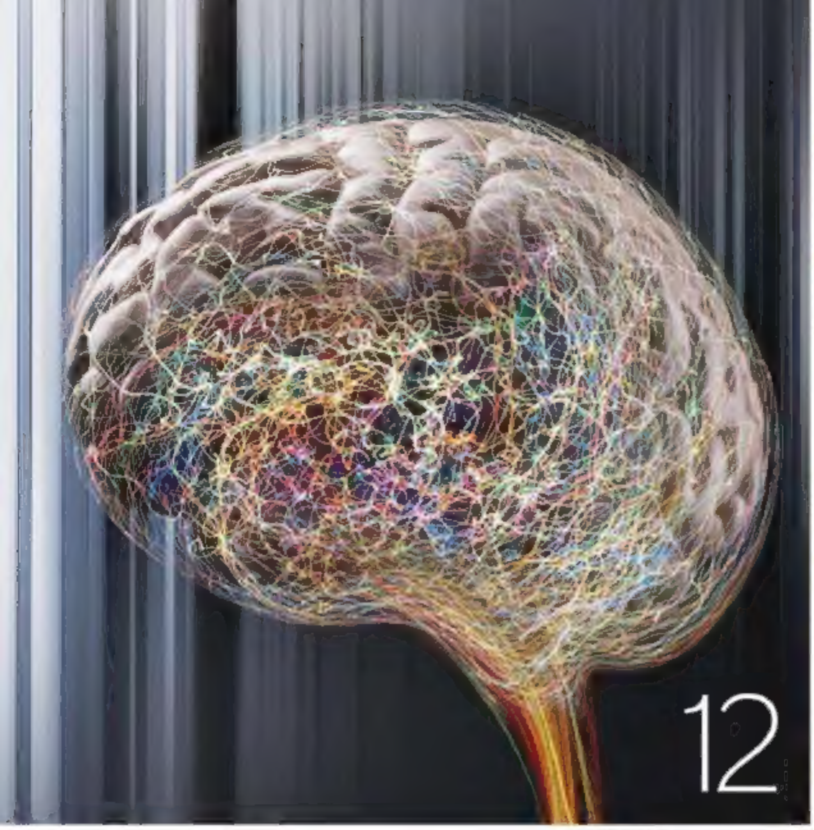
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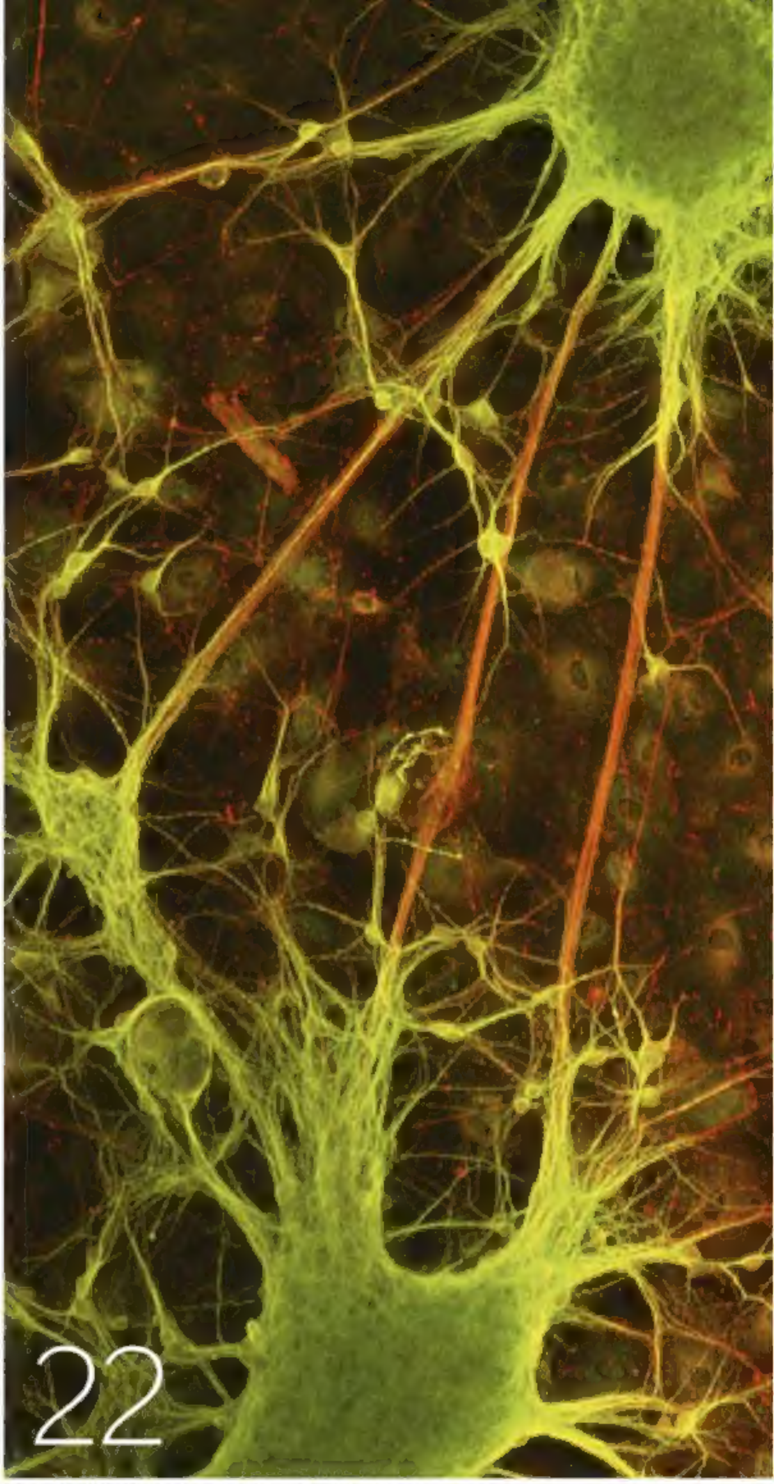
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THE HISTORY OF BRAIN RESEARCH

Doctors and neuroscientists have been attempting to unravel the secrets of the brain for centuries – but it has proved a tough nut to crack. **CHRISTIAN JARRETT** charts the major discoveries

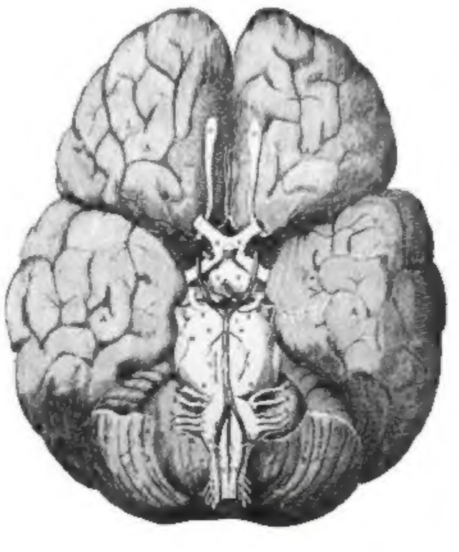
Rome, 2nd century AD. An audience of philosophers and politicians has gathered to watch Galen of Pergamon, the 'prince of physicians', perform a public demonstration involving a pig. The animal's squealing falls suddenly silent as Galen severs its laryngeal nerve – the neural link connecting its voice box to its brain. The crowd audibly gasps with astonishment. Why were they so shocked? Galen had just proved that the brain, not the heart, controls behaviour.

This might not sound ground-breaking to our modern ears, but the historian Charles Gross describes it as "one of the most famous single physiological demonstrations of all time". Although Galen wasn't the first to recognise the functional importance of the brain, he was the first to carry out a public experiment supporting his case. In Galen's time, the 'cardiocentric view' – the idea that thought, mind and soul are located in the heart – remained dominant, and would do so for centuries. You'll notice that its legacy lives on today, whenever we use sayings such as "learn things by heart."

The pig demonstration reflects in miniature the longer story of how we've come to understand the brain – it's a tale of colourful characters, ghoulish experiments and stubborn myths.

Curds and spirits

Throughout much of history, our understanding of the brain was often more of a philosophical than a scientific pursuit. This is partly because, until the last century, the biological study of our grey matter was mostly dependent on post-mortem investigations of animal brains and bodies, and only more rarely – thanks to a long-running church ban – human brains. It's amazing to think that as late as 1652, the philosopher Henry More wrote that the brain had no more capacity for thought than "a cake of suet or a bowl of curds".



Christopher Wren's highly detailed illustrations complemented Thomas Willis's writings about the brain's anatomy

One of the most influential brain dissectors who helped overturn these beliefs was the English doctor Thomas Willis. He authored the magisterial book *Anatomy Of The Brain*, published in 1664. Willis made astute and visionary arguments that complex mental functions are carried out by the cerebral cortex. This part of the brain had long been seen as little more than a useless 'rind' – cortex means 'rind' or 'husk' in Latin.

The continuing lack of scientific knowledge about the brain allowed mistaken theories to survive until relatively recently – theories that seem absurd by modern standards. For

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LIGHT SHOW
Even as late as the 17th century, some people thought the brain was a flabby organ, incapable of thought. But as this artist's impression of a human brain shows, the organ is filled with a stunning array of nerve cells (neurons), each playing its vital part in helping the brain to regulate and control the mind and body

GREG DUNN

example, another long-running belief (this one strongly endorsed by Galen) was that the brain pumps 'animal spirits' around the body.

Our leading physicians and scientists believed right up until the 18th century that nerves were filled with these animal spirits – bizarre entities that the philosopher René Descartes described as "a very fine wind". The breakthrough that led to this idea being overturned had to do with electricity, and specifically the emergence of 'electrotherapy' as a treatment for paralysis.

Public demonstrations again played their part in changing minds. In an event held in 1803 in London, for example, Giovanni Aldini (nephew of the pioneering anatomist Luigi Galvani) applied electricity to George Forster's brain to show how it caused the muscles of his face to twitch. Forster didn't know much about this – he'd just been hanged for the murder of his wife and child. But for the audience it helped to show how electricity was part of the way that nerves communicate.

In 1803, Giovanni Aldini applied electricity to George Forster's brain to show how it caused the muscles of his face to twitch

However, even as the scientific establishment came to recognise the functional significance of the brain, and especially the cerebral cortex, another mistaken dogma persisted – the idea that mental functions, such as language, are distributed uniformly throughout the cortex rather than being partly localised in specific regions.

One historical patient played a particularly important role in helping to overturn this idea. His name was Louis Victor Leborgne, but he was nicknamed 'Tan', because this was →

Previously, researchers had to make assumptions. With EEG they could see how different brain regions became more active

virtually the only word he could utter. At autopsy, the French neurologist Paul Broca discovered that Leborgne had highly localised damage to a region in his left frontal cortex, known today as Broca's area, and he inferred that the damaged region must play an important role in speech.

Broca's presentation of Leborgne's case to the Société d'Anthropologie and the Société Anatomique in 1861 was instrumental in convincing the academic community that language function is particularly dependent on the frontal lobes. The historian Stanley Finger describes this moment as a "key turning point in the history of the brain sciences". Patients like Leborgne, with particular mental or physical deficits tied to specific areas of brain damage, have been one of the most important sources of information about the workings of the brain, and this is still true today.

At the end of the 19th century, brain science was focused once again on the perplexing issue of how exactly nerves manage to communicate with each other. While the earlier realisation of electricity's role had helped to debunk the notion of animal spirits, it was clear that there was more to nerve communication.

Nervous science

We know today that electrical current along a nerve cell (neuron) causes it to release chemicals across a tiny gap – a synapse – and these chemicals, known as neurotransmitters, are then picked up on the other side by the receiving neuron. However, in the late 1800s, even the best microscopes and staining methods were incapable of revealing the presence of these gaps between neurons. This led the Italian scientist Camillo Golgi and his contemporaries to propose that nerves are fused together – an erroneous idea known as the 'reticular theory' (from the Latin for 'net').

It was the Spanish neuroscientist Santiago Ramón y Cajal who killed off the nerve net idea thanks to his advances in cell staining techniques, which made it clear that neurons are not joined together after all.

In the 20th century, technology began to play an increasingly important role in advancing our knowledge of the brain, particularly by allowing psychologists and neuroscientists to monitor brain activity. In the 1920s, scientists started to use electroencephalography (EEG), which involves recording electricity emitted by the brain through electrodes placed on the scalp. Previously, researchers had to make assumptions about the location of different mental functions based on the effects of brain injury and by looking for patterns of damage at post-mortem. With EEG they could see how different regions of the brain become more active depending on

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Timeline Brain science

425 BC
The Hippocratic treatise On the Sacred Disease states, contrary to the dominant cardiocentric view, that "from the brain and the brain only arise our pleasures, joys, laughter and jests, as well as our sorrows, pains, griefs and tears."

Galen of Pergamon
(c.130-210)
In the 2nd century, the philosopher performs the pig demonstration (see page 6), showing that the brain controls behaviour.

1543
Renaissance anatomist Andreas Vesalius publishes his landmark book *On The Fabric Of The Human Body*, showing some of the most detailed dissections of the human brain ever produced.

1830s
Phrenology reaches the peak of its popularity. This was the mistaken idea that psychological aptitudes and personality traits can be discerned from the bumps on someone's skull.

1848
Railway worker Phineas Gage becomes one of the most famous patients in neuroscience after surviving an accident in which an iron rod passes straight through the front of his brain.

what the person was saying, thinking or doing. But the problem with EEG is that while it provides good temporal resolution – revealing changes in brain activity from one millisecond to the next – its spatial resolution is crude. This limitation was overcome in the 1960s with the advent of positron emission tomography (PET), which allowed researchers to monitor changing patterns of blood flow in the brain in high resolution. Things progressed even further in the 1990s with the emergence of functional magnetic resonance imaging (fMRI), which also has good spatial resolution but, unlike PET, does not require the injection of a radioactive isotope.

fMRI has had a huge influence on the study of the brain, and is now the principal technique used in the increasingly dominant field of cognitive neuroscience, merging psychological and biological approaches to brain function. These are the kinds of studies that lead to colourful images of 'blobs on the brain', where the blobs usually illustrate areas thought to contain heightened activity as the participant performs different tasks. In 2013, a review of the field estimated that over 130,000 fMRI research studies had been published, a figure that will by now be substantially higher.

Quadriplegic Jan Scheuermann uses thought to control a robotic arm

The next step

Increasingly sophisticated methods for recording and decoding brain activity have helped contribute to important neuroscience breakthroughs in recent years. For example, there has been huge progress in brain-machine interfaces, which enable paralysed people to control computer cursors or prosthetic limbs using thought alone.

Other research has shown that it's possible to use recorded brain activity patterns to communicate with some patients who were previously thought to be in a non-communicative, persistent vegetative state.

But, although we've made great strides in our understanding of the brain, the truth is that we've barely scratched the surface. And, sadly, devastating illnesses like Alzheimer's (see page 82) and motor neurone disease still remain incurable.

Let's hope this changes with the record levels of investment being plowed into ambitious new neuroscience research programmes, such as the BRAIN Initiative in the US and the Human Brain Project in Europe (see page 108). A key player in the latter project is neuroscientist and entrepreneur Henry Markram, who in a TED talk said: "It is not impossible to build a human brain, and we can do it in 10 years." That was in 2009. In three years' time, we'll find out if he was right. ■

Alois Alzheimer (1864-1915)
In 1901, the German psychiatrist makes detailed notes on Auguste Deter, the first person diagnosed with Alzheimer's disease. "I have lost myself," she tells him.

Santiago Ramón y Cajal (1852-1934)
In 1913, the Spanish neuroscientist publishes *Degeneration And Regeneration Of The Nervous System*, detailing his groundbreaking findings on brain injury and recovery. But he also claimed in error that new neurons do not grow in adult brains.

1953
Patient Henry Molaison undergoes brain surgery for intractable epilepsy. The procedure leaves him with profound amnesia and he becomes one of neuroscience's most studied individuals.

Oliver Sacks (1933-2015)
In 1985, British neurologist Oliver Sacks publishes his best-selling book *The Man Who Mistook His Wife For A Hat*. He becomes renowned for chronicling the human stories of brain illness and injury.

2013
President Barack Obama launches the BRAIN Initiative. "As humans, we can identify galaxies light-years away, we can study particles smaller than an atom. But we still haven't unlocked the mystery of the three pounds of matter that sits between our ears."

NEUROS

THE NEUROLOGY AND PSYCHOLOGY OF THE BRAIN

HOW YOUR BRAIN WORKS
The anatomy of your little grey cells

WHAT MAKES YOU *YOU*
How the brain shapes personality

FREE WILL
Are you really in control?

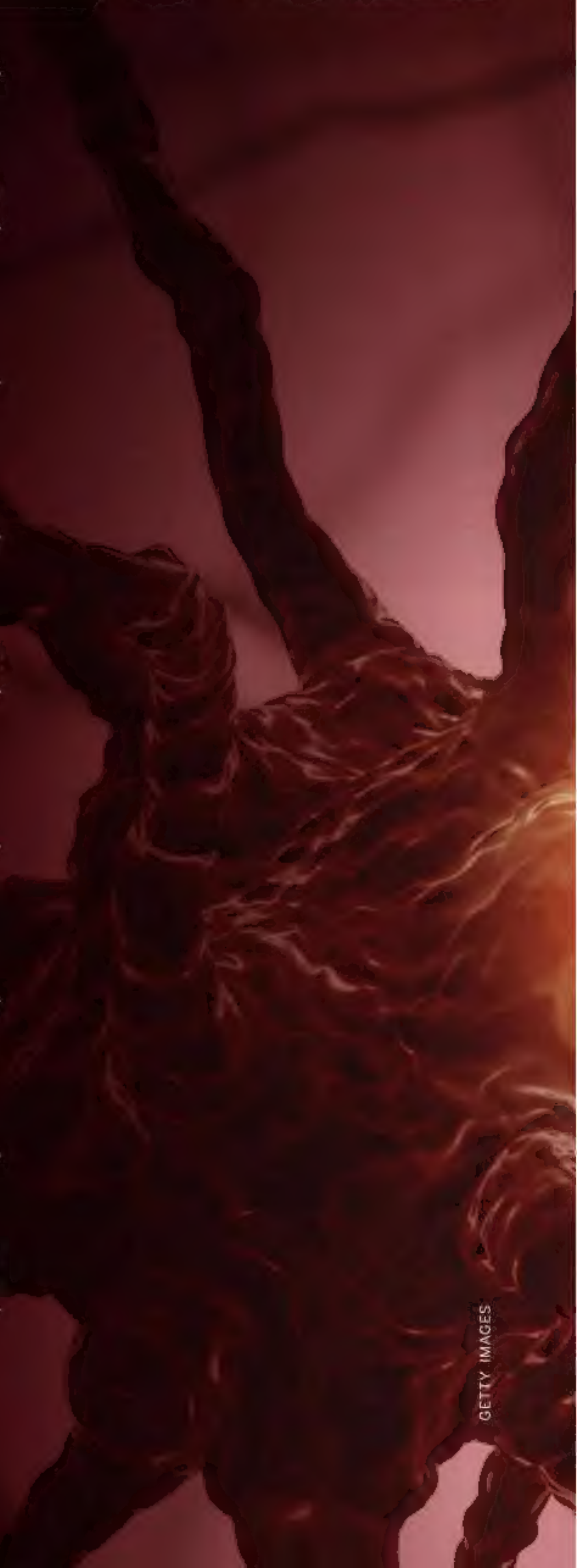
MEMORY GAME
How science can change memories

MALE VS. FEMALE BRAIN
We're not that different after all

WHY POWER CORRUPTS
The psychology behind dictators

EVOLUTION OF INTELLIGENCE
Why some animals are smarter

INSIDE THE MINDS OF DOGS
Why pooches are man's best friend



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CIENCE

HOW YOUR BRAIN WORKS

Some say we know more about the ocean depths and distant cosmos than we do about the inner workings of our minds. **RITA CARTER** reveals what we currently do know about the brain

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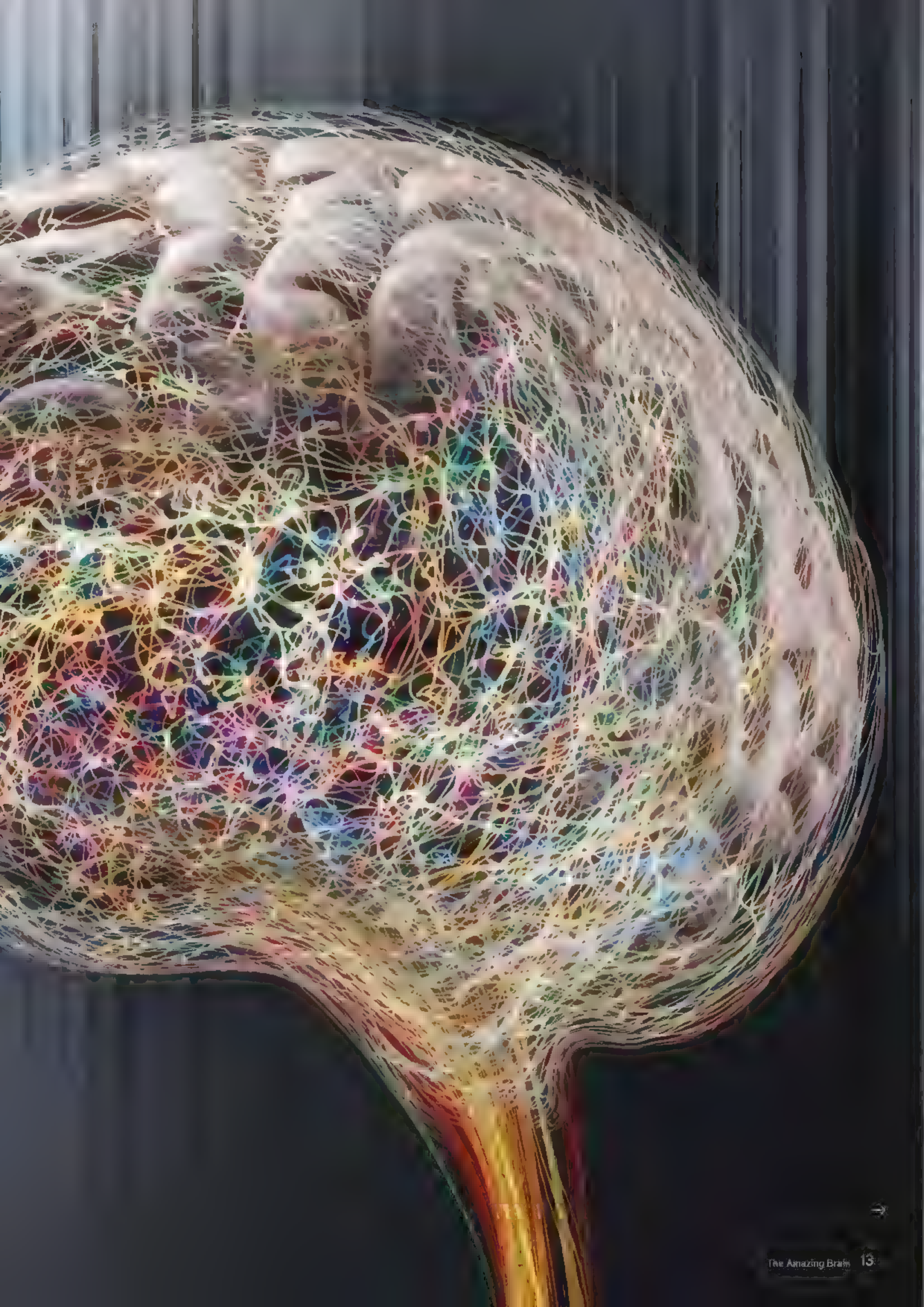
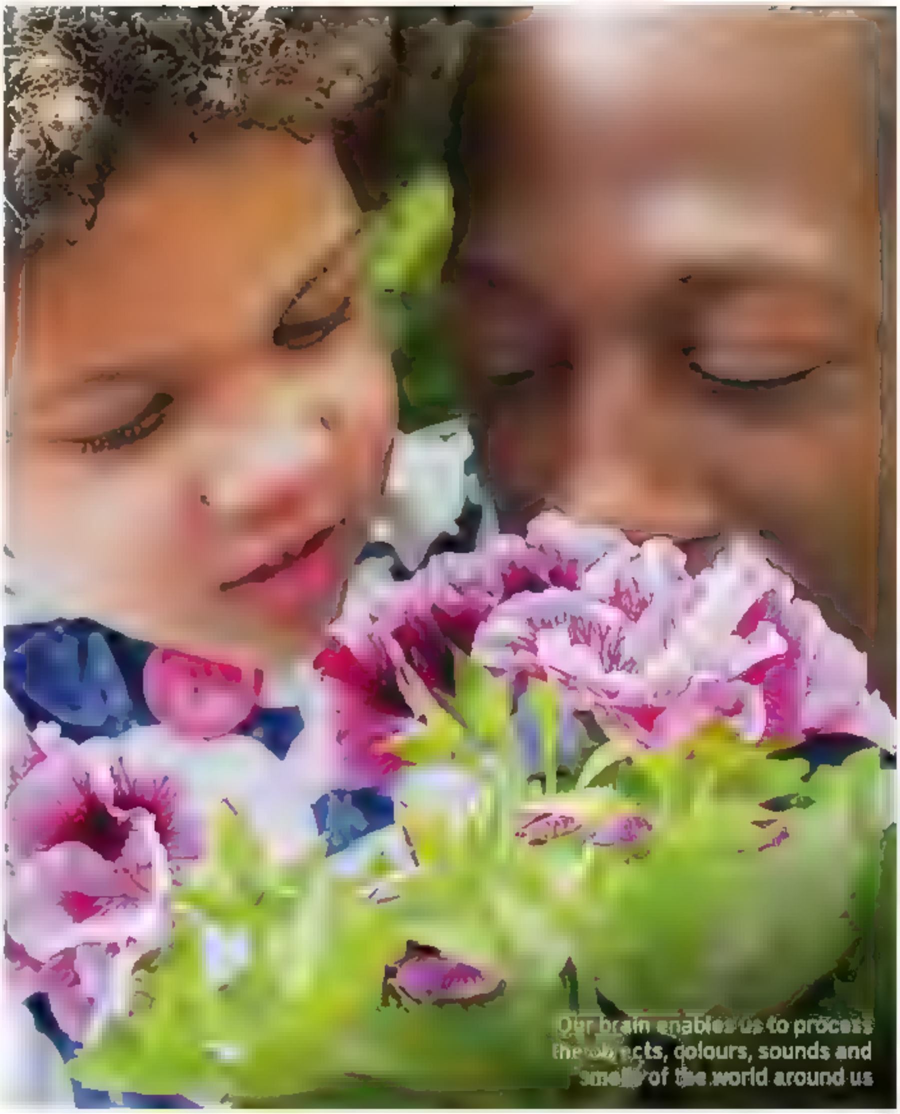


The brain is an electrical device which generates every one of our sensations, thoughts, feelings and actions. Incredibly, it does all this on slightly less power than that used by a 60 watt lightbulb. Its primary purpose is to keep us alive by regulating and orchestrating our responses to the outside world. Most brain functions, such as adjusting heartbeat and triggering the release of hormones, occur without us knowing. However, some brain work has a special quality – consciousness.

Conscious awareness feels effortless, but the mechanisms underlying it are immensely complicated. The brain doesn't just make us aware of our surroundings – it constructs them.

The world seems to consist of objects, colours, sounds and smells. All that's really there, though, is light rays and sound waves, jittering atoms and vibrating molecules, all of which continuously bombard our bodies. The brain transforms these stimuli into familiar perceptions through a complex and surprisingly lengthy process. Up to half a second elapses, for instance, between light arriving at the eye and the emergence of a conscious image. If something goes wrong during that pre-conscious half second the result can be very strange. A person may see or hear things that are not there or fail to recognise what is. They might mistake familiar friends for strangers, or be unable to identify common objects.

One way to look at conscious processing is to think of the brain as a factory assembling 'qualia' – elements of consciousness – from the raw material of various types of stimuli.



Our brain enables us to process the objects, colours, sounds and smells of the world around us

The brain's primary purpose is to keep us alive by regulating and orchestrating our responses to the outside world

It starts when a stimulus impacts a sense organ, such as the eye or ear. The organ reacts by generating an electrical signal which it directs along neuronal pathways – fibres made from interlinked electrical cells – to specialised brain areas. Retinal cells react to light, for example, sending a current of electricity down neural pathways to the occipital lobe at the back. Cells in the ear turn pressure waves into currents, which travel to the auditory cortex in the temporal lobe. And receptors in the nose react to certain molecules, and trigger activity in a deeply buried part of the frontal lobe. Long, snaking nerves which run down the spinal cord to the skin and muscles react to touch and pressure, and send signals back to the somatosensory cortex, a strip of tissue which curves around the top of the brain, like an Alice band.

Once these signals reach the appropriate brain area, the business of transformation begins.

The construction of a conscious visual image starts when the →

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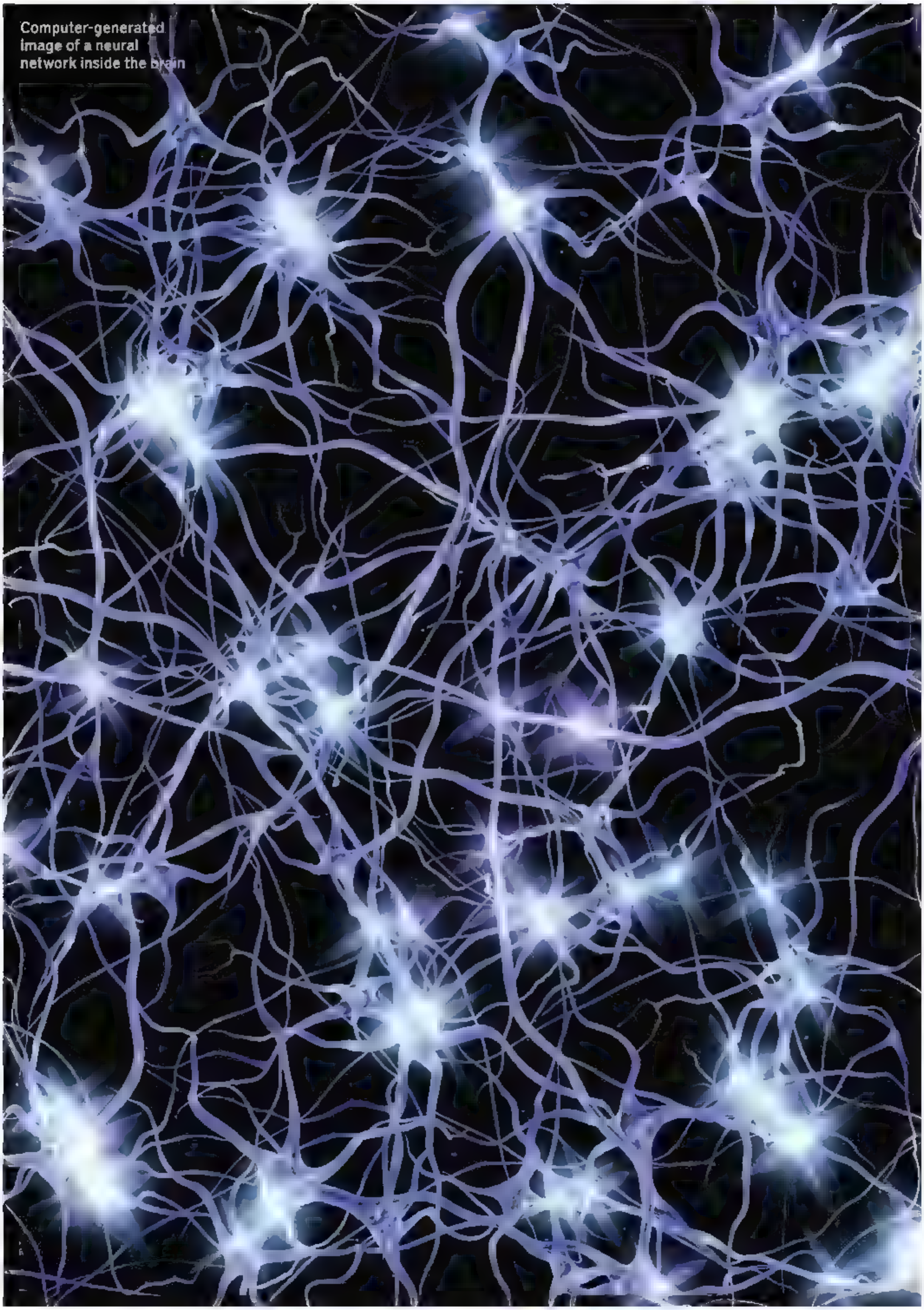

Computer-generated image of a neural network inside the brain

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light-generated electrical impulses travel back from the eye along neural pathways called the optic nerves. About halfway through the brain the signals pass through the thalamus. This important brain nucleus acts like a relay station, receiving most incoming information and shunting it on to the right brain areas. It pushes most visual information on to the occipital lobe at the very back of the brain, but it diverts a little of it to the parietal cortex, close to the area concerned with action. This diversion creates an extraordinary effect – we 'know' what our eyes have registered without actually seeing it.

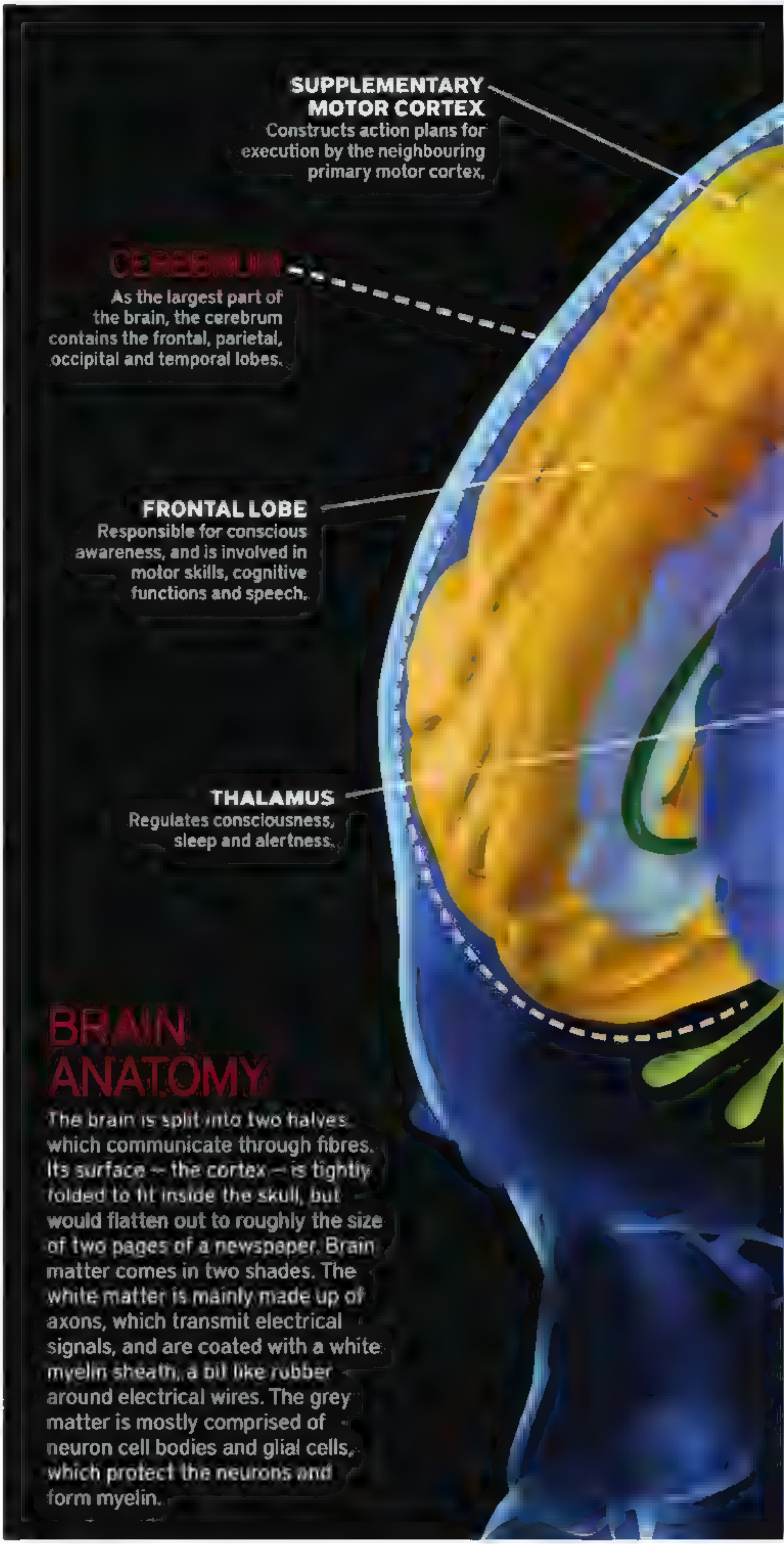
Blindsight route

The phenomenon is known as 'blindsight' and it is observed most easily in people who are – in the ordinary sense – blind. Although they protest they cannot see, if forced to 'guess' where an object is by pointing at it, such people often get it right, to their own astonishment. This is because the diverted signals activate parietal neurons, which orient us to targets. We don't consciously know what is there, but our brain does, and directs our body towards it.

Research on blindsight shows that it is not just an object's position in space that can be detected this way. One blindsighter can tell the shape, colour and trajectory of a target and even read the expression on an 'invisible' face. Another can recognise faces even though he can't see them consciously at all.

Blindsight has also been demonstrated in people with normal vision. It probably accounts for things like the ability of crack tennis players to hit balls travelling too fast to be seen in the normal way.

Back on the main pathway, →



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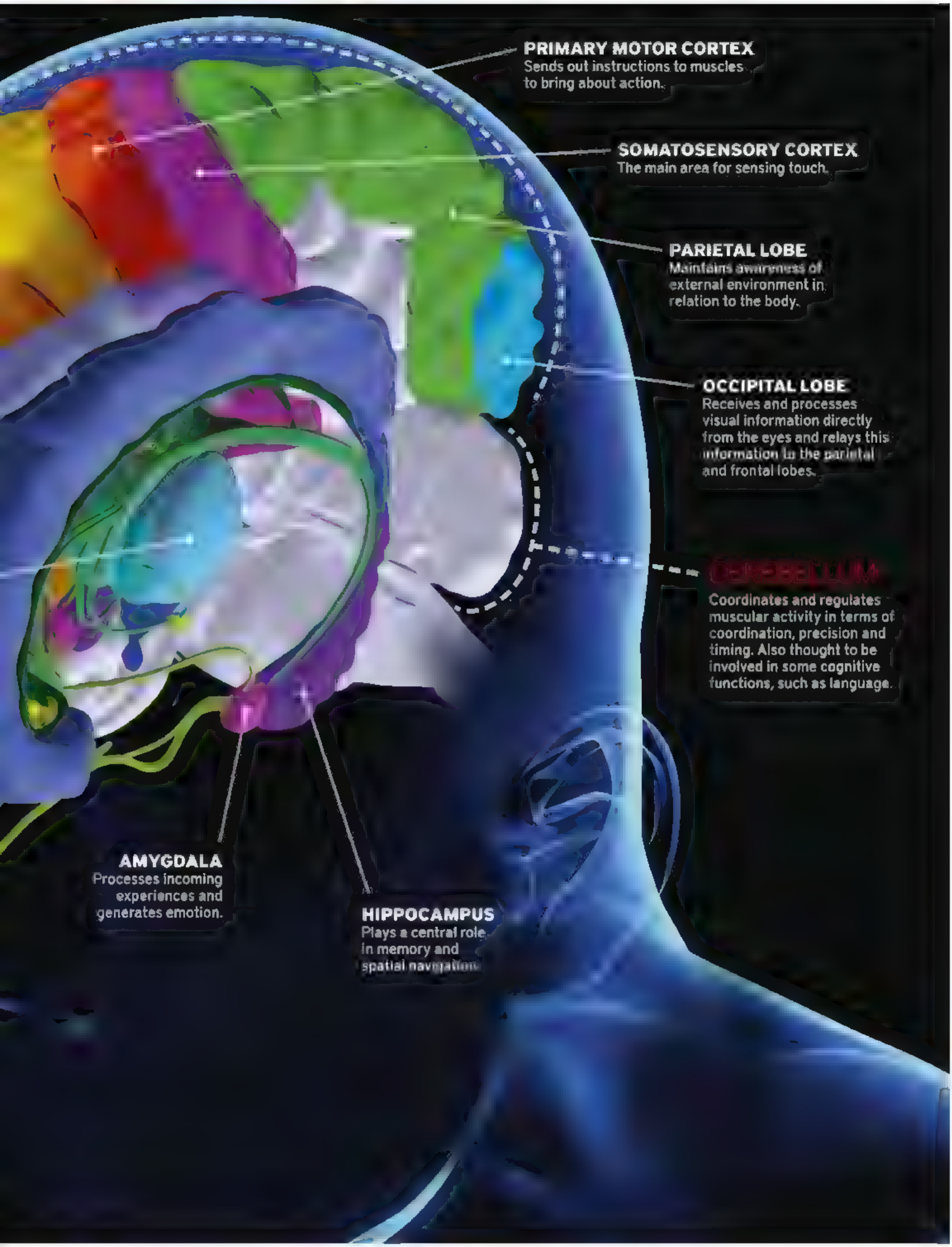
PRIMARY MOTOR CORTEX
Sends out instructions to muscles to bring about action.
SOMATOSENSORY CORTEX
The main area for sensing touch.
PARIETAL LOBE
Maintains awareness of external environment in relation to the body.
OCCIPITAL LOBE
Receives and processes visual information directly from the eyes and relays this information to the parietal and frontal lobes.
CEREBELLUM
Coordinates and regulates muscular activity in terms of coordination, precision and timing. Also thought to be involved in some cognitive functions, such as language.
AMYGDALA
Processes incoming experiences and generates emotion.
HIPPOCAMPUS
Plays a central role in memory and spatial navigation.

The 'blindsight' phenomenon is thought to be the reason tennis players are able to react to balls that appear to move too fast for the human eye to see

most signals from the eyes go to the occipital lobe at the back of the brain. This is made up of smaller areas, each of which specialises in one or another element of vision. The motion area, for example, discerns signals which encode movement, while another area responds to colours, and others to edges, depth and so on.

First stop for incoming visual information is the primary visual cortex, or V1 – a sort of checking-in depot for visual information, which lies at the very back of the brain. V1 registers that something potentially visual has come in and then pushes the electrical signals back towards the front of the brain. It is a little bit like the factory conveyor belt has done a U-turn.

In quick succession, the information passes through the specialised visual areas, each of which detects and amplifies their relevant thing – such as colour or movement. This turns the signals from simply a visual stimulus to one endowed with qualities, such as red, spherical and moving, or square, black and static. As it travels through the occipital lobe, the information splits and continues its travels along several divergent pathways. One of the routes goes up and over the brain to the parietal cortex, while another ducks along the bottom edge of the temporal lobe.

Prosopagnosics may not even recognise their own partners – a situation fraught with potential disaster

The 'what?' pathway

The lower route is known as the 'what?' pathway, because it goes through those parts of the brain which, bit by bit, build the information into a recognisable, and possibly conscious image.

The temporal lobe is the part of the brain where long-term memories are encoded and retrieved. Memories reside in networks of interconnected neurons. To be precise these are potential memories – the experience that formed them is only brought to mind if electricity sparks up in the

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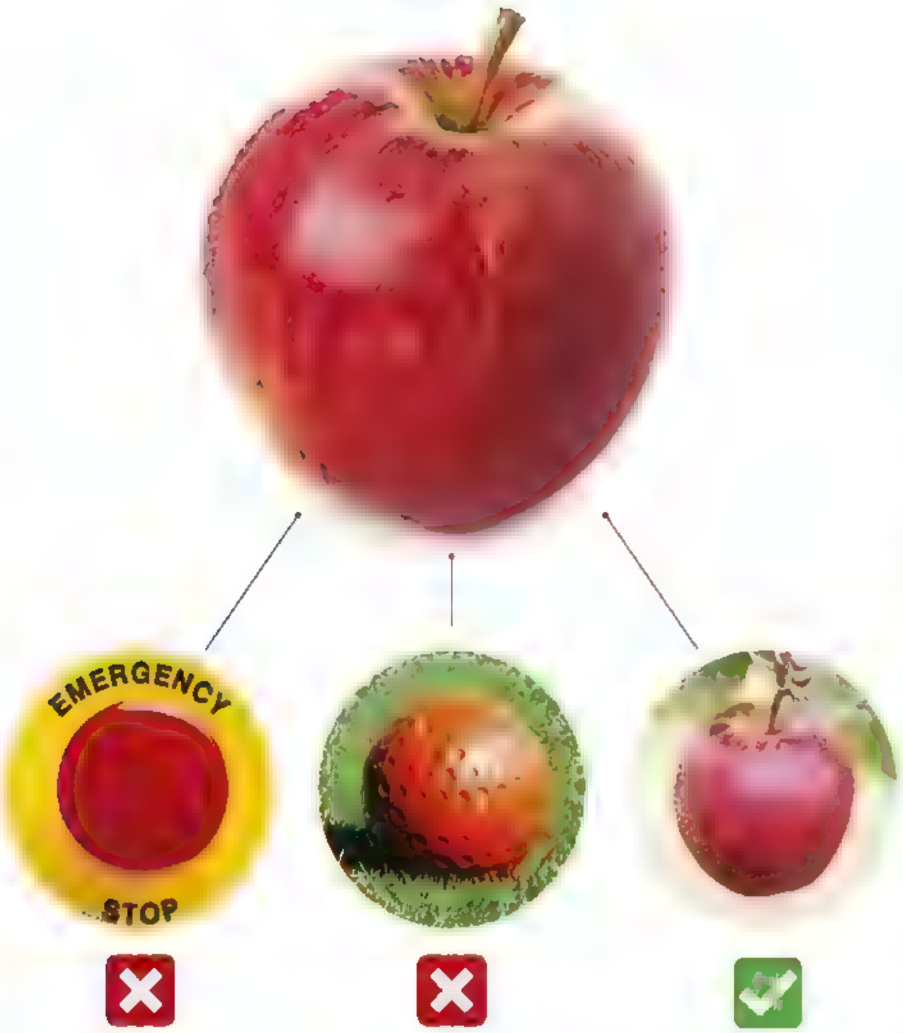

TOTAL RECALL When trying to identify an object, the brain relies on previous experience. A new event maps on to a memory, thereby activating the same neurons as before, for example, identifying a red, round object as an apple

network and sets the neurons in it firing. Such activation occurs when a novel event maps on to a memory by activating some of the same neurons as the previous experience. For instance, if an incoming signal has been 'tagged' by the visual colour area as red, and the shape area as round, it will trigger ignition in the 'red and round-detecting' neurons in memory networks formed by previous experiences of red, round things. Hence, the new information may bring to mind apples, red balls and alarm buttons. The one that most closely matches the current information will then be attached to it, so the signal moves forward as 'apple', rather than just 'red and round'.

This (still unconscious) matching of new information to old is crucial for recognition and, if it fails, the effect can be weird. A person may be able to see an object, describe it, draw it, and even use it – yet be unable to identify it. "A brush?" queried one such person, in response to a carrot. And (confidently) to a picture of a nose: "Ah – a soup ladle!"

'Agnosia', as it is called, varies widely according to which stage of temporal lobe processing is compromised. One section of the 'what?' pathway deals exclusively with distinguishing people. The late Oliver Sacks wrote of a college professor with damage to this area who "genially, Magoo-like... might pat the heads of water hydrants and parking meters, taking these to be the heads of children...[and]...would amiably address carved knobs on the furniture and be astounded when they did not reply". More commonly, people know when they are looking at a person, but cannot distinguish one face from another, a condition known as 'prosopagnosia'. Prosopagnosics may not even recognise their own partners – a situation fraught with potential disaster.

The intriguing case of HM

Further along the 'what?' pathway, visual signals are matched to personal rather than merely generic memories. An object tagged so far as a face, for instance, may now become 'Bob's face'.

This type of recognition happens as the signals pass by what is known as the hippocampus, a tiny nugget of tissue which is responsible for both recording and recalling personal experiences. Its central role in memory makes hippocampal damage potentially catastrophic.

The case that most clearly demonstrated this is that of Henry Molaison, known to generations of psychology students as 'HM'. As a young man Mr. Molaison suffered severe epilepsy, and in 1953 doctors removed a large section of his brain to prevent the seizures from spreading uncontrollably. Unfortunately the area they removed included his hippocami and, although the surgery succeeded in stopping his seizures, it completely robbed HM of his ability to lay down any new memories. He experienced his long life, apparently fairly normally, from moment to moment, but the experiences did not stick. In his head he remained the young man he was before surgery and, however many times he met a person, he never remembered them. Indeed, if he was distracted for just a few seconds, his memory of what he was doing and who he was talking to evaporated.

One of the many researchers who introduced herself to Henry time and →

Surgery to remove a large portion of Henry Molaison's brain stopped his epileptic seizures, but also caused brain damage, preventing him creating long-term memories

again was Suzanne Corkin, who was Professor of Behavioral Neuroscience and Head of the Corkin Lab at the Massachusetts Institute of Technology before her death in May this year. Corkin recalled that Henry loved to relate his few clear memories of his childhood, over and over, though he lacked a context for them, and the face he surprised himself with in the mirror each morning did not quite connect with them.

"The interesting and important thing scientifically about these stories was that he would give you the gist of them, but they were never linked to a specific time and place," Corkin told *The Guardian* in 2013. "You and I can say what we did on our last birthday. But Henry could never remember what else happened. There were no connections, no associations for him in that way."

HM retained some types of memory – he learned to play new tunes on the piano, but without any recollection of learning them

Yet HM retained some types of memory – he learned to play new tunes on the piano, for instance, but without any recollection of learning them. So, as well as illuminating the crucial function of the hippocampus, his case helped researchers to tease apart and locate the structures involved in different types of memory – long and short term, semantic and episodic – which together allow us to navigate the world.

The hippocampus is one of the areas most affected in Alzheimer's dementia, but other than that damage to it is mercifully rare – most memory lapses are due simply to inattention.

Indeed, inattention prevents the vast majority of incoming information from becoming conscious. Only very strong signals – those which grab attention – continue from the temporal lobe to the end of the 'what?' pathway, in the brain's frontal lobe.

The frontal lobe is the part of the brain responsible for conscious awareness. Thoughts, emotions and

JENN OGDEN

– as we have seen, perceptions are constructed in unconscious areas further back, but if they get pushed forward to the frontal area we may become aware of them.

It's not necessary, though, for us to be conscious of something in order to act on it. Indeed, sometimes consciousness can be positively disadvantageous – think of what happens on a dance floor when we become conscious of what our feet are doing. Hence, our bodies may act on information long before it finishes that tortuous journey along the 'what?' route.

The 'where?' pathway

While some signals travel along the 'what?' pathway, other versions of the information shoot along faster routes. One is the upper or dorsal stream, which ends in the parietal cortex. This is commonly known as the 'where?' pathway, because the areas it passes through are concerned with physically acting on the information, rather than working out what it is. The speed of the 'where?' pathway (part of which joins with the blindsight route) means that your body is primed and ready to act on new information long before it becomes conscious.

Another fast track carries signals through the amygdala. This tiny nucleus 'tastes' all incoming experience and reacts to it by generating appropriate emotion. Emotions are primarily bodily reactions – the feelings we call 'sadness' or 'joy' are just our conscious knowledge of physical changes that have already occurred.

"Conscious emotion is in a way a red herring," says Professor Joseph LeDoux of New York University, an expert on the amygdala. "Emotions are things that happen to us rather than things we make happen. We try to manipulate our emotions, but all we are doing is arranging the outside world so it triggers certain emotions – we cannot control our emotions directly. Our feelings often push out thinking, whereas thinking fights a mainly losing battle with emotions."

The amygdala helps us to evaluate information as 'good' or 'bad', kicking us into action, such as running from a snake

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Incoming information is 'tagged' as good or bad by the amygdala about a quarter of a second before we are conscious of it. And, as we have seen, the 'where?' pathway ensures that our bodies are primed to act on it in about the same time. So if the amygdala evaluates an event as 'bad' we may move away from it, or hit out at it before we know consciously that it is there. A snake in the grass can set us running away and, conversely, signals from a smiling face will start our own smile muscles twitching even if the face it decorates turns out to be Hitler's. These unconscious reactions play a huge part in what we think of as decision-making. Conscious, deliberated actions – going somewhere on vacation, or taking a particular job – are similarly driven largely by unconscious processes, but they also involve activation of parts of the frontal lobes.

As we have seen, some of the processes that occur here have that strange quality of consciousness, and the fact that we are aware of the grinding cognition involved in conscious decision-making tends to give us the illusion of controlling it. In fact, what we call 'decisions' may just be a special kind of awareness – that of the brain going about its continuous, complicated business of regulating, controlling and directing our bodies.

WHAT MAKES YOU **YOU?**

Your brain is the most complex organ in your body – a mass of billions of neurons that keep you alive. **RITA CARTER** reveals how your genes and the outside world influence your little grey cells, shaping your personality and behaviour

One afternoon in 1848, on a railroad construction site in Vermont, a dynamite blast launched an iron rod into the air, spearing foreman Phineas Gage through the head. Incredibly, Gage survived his injuries but – deprived of a large part of his frontal lobe – his previously conscientious, agreeable personality did not. Gage became disinhibited, impulsive and rude.

Gage's story is familiar to every Psychology 101 student, because it provided one of the earliest and most dramatic demonstrations of the physicality of human personality. It also demonstrated how easily, and quickly, it can be changed. Since Gage it has become increasingly clear that the apparently 'essential' ways of thinking and behaving that identify each individual is a product of the functioning and structure of their brain. It has also become clear that you don't have to blow a hole in your head to change your personality. Brains are astonishingly plastic and, in some cases, all it takes to transform a person is to give them a tiny zap of electric current.

No laughing matter

Edi Guyton is an American academic who, though professionally successful and surrounded by a close-knit, loving family, spent the vast majority of her life sunk in depression. Her first suicide attempt was at the age of 19 both wrists. She tried drugs, ECT and years of talk therapy, but nothing prompted her to smile or laugh. Her pessimism and joylessness were not linked to events, they seemed to be central to her personality. Even the arrival of a cute grand-niece, Susan, didn't lift her spirits. "People would hand her to me and I would hold her and go through the motions," she says. "But I felt nothing."

But, in 2007, Edi completely changed – in a matter of seconds. This video clip (www.youtube.com/watch?v=Lq5rIILcVgA) shows Edi laying on an operating bed, fully conscious, surrounded by a team of surgeons. One of them has made a couple of holes in her skull and threaded two electrodes, connected to angel-hair wires, into a deeply-buried region of her brain, known as Brodmann's area 25. They ask Edi what she is feeling. "Dread," she says. "Rate it," says one of the team. "Eight," says Edi.

Then they turn on the power. "What's the dread now?" someone asks. "Three," says Edi. The surgeon makes a minute alteration to the position of the electrodes. Edi makes an unmistakable sound. "She's laughing," says someone.

Later Edi told Dr. Sanjay Gupta, the CNN medical correspondent who compiled the report: "Right there in that brain surgery I felt feelings that I thought were gone. I started thinking about holding and playing with Susan. It felt fantastic."

The effect has lasted – years later, Edi remains transformed. Although she still has bad days, generally she is now a normal, cheerful person.

Deep brain stimulation is most commonly and successfully used to control tremors caused by burned out dopamine circuits in the brains of people with Parkinson's disease. In

Phineas Gage holding the iron rod that drove a hole through his skull during a dynamite explosion

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Sociable people have more tissue in the area of the frontal cortex concerned with processing reward information

addition to depression, though, it has had some success as a treatment for Obsessive Compulsive Disorder, which is caused by overactivity in brain circuits concerned with vigilance and other basic functions.

The technique is by no means a magic wand, because there are risks in the surgery itself, and brains are so complicated that what works for one person does not always work for another. Indeed, Edi's operation was part of a trial that was in many ways a failure, with a problem-free success rate of less than 20 per cent. Nevertheless, Edi's experience, and dozens of similar cases, demonstrate that even the most deep-seated behaviours can be changed by very small physical interventions.

Molding personality

The fact that behaviour can be changed should not be surprising, because the correlation between brain function and personality has been demonstrated in hundreds of brain-imaging studies. Neuroscientists at Stanford University, for example, showed that people who are extroverts show quite different brain activity to introverts when shown emotional images. Another study showed that someone's personality is stamped on their brain, even when they are not actually doing anything. Yale researchers looked at the activity in various brain regions in 126 people while they let their minds wander, and measured how strongly the activity of each region compared to the activity in every other region. By doing this they created a personality pattern for each person, and found every one was entirely distinct.

Next, to test their discovery, the team worked backwards – they searched through scans from previous sessions to see if they could identify each person based on their pattern. They found they could pinpoint each participant with surprising accuracy, even among the twin volunteers who took part.

"The area of the brain where people differed most was the frontoparietal network – the parts which connect perceptions to the thinking and planning areas in the front of the brain," says Todd Constable, senior author of the study. "It's the most recently evolved part of the brain and the bit that makes humans distinct from animals."

Another researcher, Colin de Young, Associate Professor at the University of Minnesota, has found that the brain regions which are most concerned with behavioural features we regard as personality traits – for example, conscientiousness and extroversion – are measurably larger in people who score highly in those traits on an ordinary pencil-and-paper-personality test. Extroverted people were found to have more tissue in the area of the frontal cortex concerned with processing reward information. Agreeableness correlated with volume in areas that process information about the intentions of →

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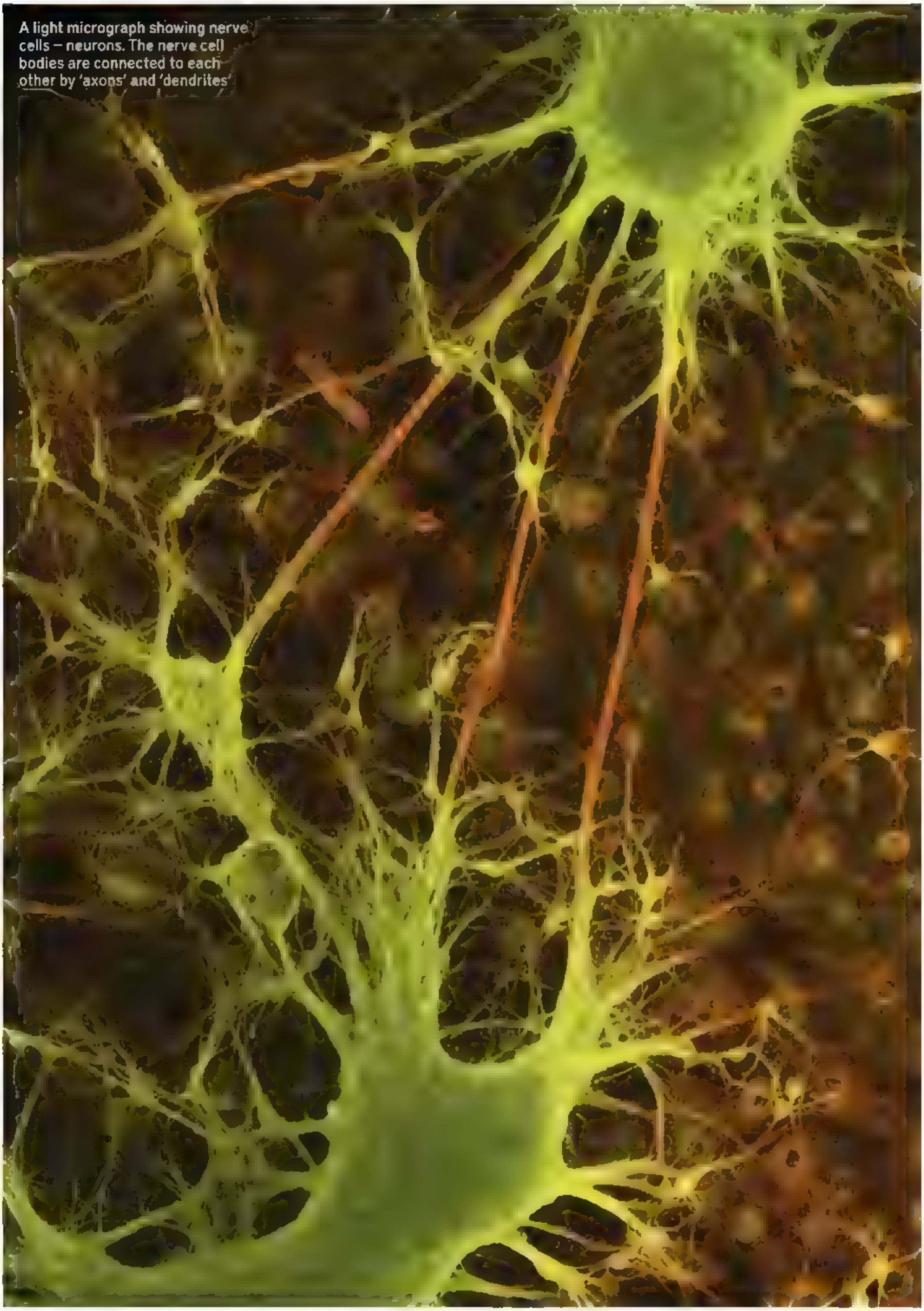
A coloured x-ray showing deep brain stimulating electrodes being used to treat symptoms of Parkinson's disease



A light micrograph showing nerve cells – neurons. The nerve cell bodies are connected to each other by 'axons' and 'dendrites'

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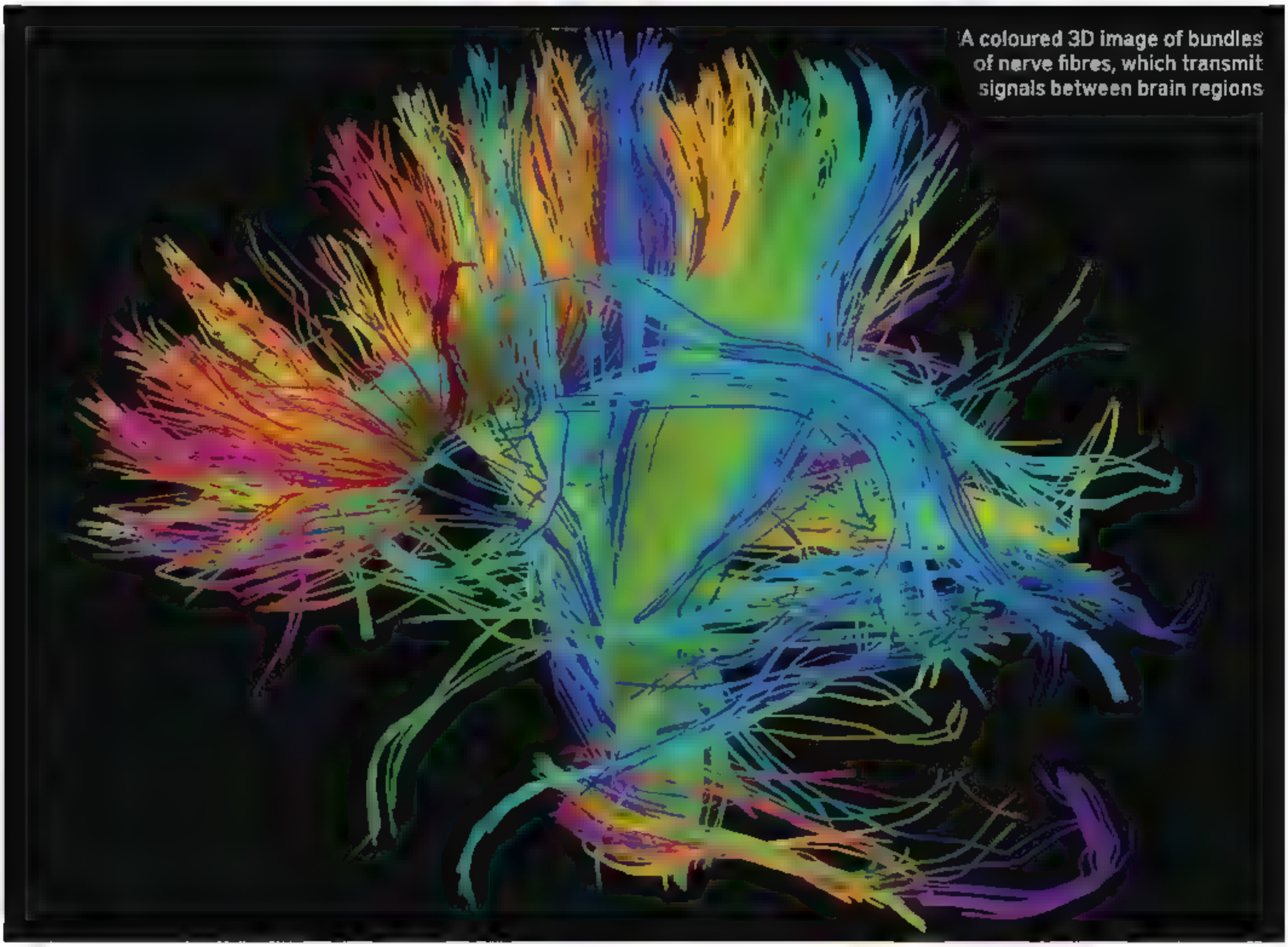


A coloured 3D image of bundles of nerve fibres, which transmit signals between brain regions

others. Neuroticism was linked with brain regions associated with threat, punishment and negative affect. And conscientiousness scores matched the size of the prefrontal cortex – planning and voluntary control of behaviour.

A whole bunch of neurons firing is a bit like a line of dancers high-kicking their legs in sequence to create a Mexican wave

Genes versus training

It is impossible to say whether the distinctions noted by de Young are the cause or effect of the individuals' personalities. The structure of the brain is partly determined by genes, but brain areas are also built up by being used, in much the same way as muscles can be enlarged through exercise. Most likely it is the interaction of both genes and the way that people use their brains that create their distinctive structure.

Beneath the wrinkled cortex, the brain is made of a dense mesh of pathways that carries electrical currents from place to place. It is known as the 'connectome'.

The connectome is made of connective tissue that extends from each nerve cell – neuron. When a neuron fires, it creates a pulsation, which suddenly changes the electrical potential. Each neuronal firing is a sort of mini-explosion and, if it is strong and frequent enough in one neuron, it kick starts neighbouring cells, causing a whole bunch of neurons to begin firing at the same rate. It's a bit like a line of dancers high-kicking their legs in sequence to create a Mexican wave. These bursts of organised activity are our sensations, thoughts and emotions.

When neurons fire together they become temporarily bonded, so that in the future when one is activated it is more likely than before to trigger activity in the others. And if the initial 'dance' is particularly energetic, or performed frequently, the neurons that take part in it change physically. Their axons – the fibres that form the connectome – extend until they are close enough to their neighbours to create a new pathway between them. It's like the dancers linking hands. Axons shrivel →

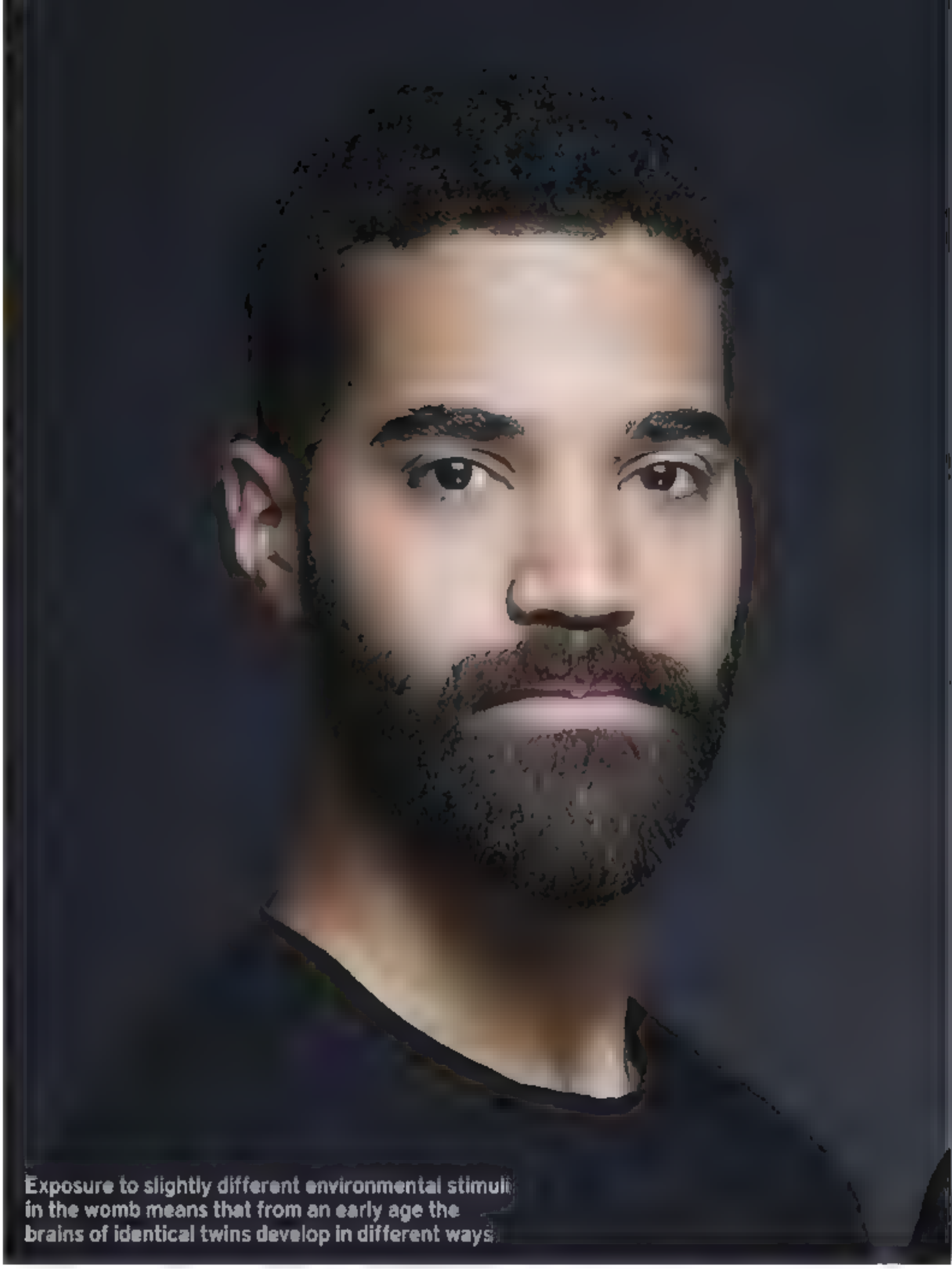
if the path they form does not regularly carry messages. If the same neurons are stimulated to dance together time and again, though, the pathways between them become firmly entrenched as the electrical current passes repeatedly through them. The paths that carry most traffic get wider and more substantial, while those that are rarely used shrink.

You will see from this that the architecture of a person's brain is partly formed by what a person does – lose their temper, laugh, feel frightened, concentrate and so on. The architecture so formed then encourages their brain to do the same things again and again. In behavioural terms it is called learning. Or, if you like, creating a habit.

Habit of a lifetime

Much of an individual's personality is simply an accretion of habits. If a person is in a job where being conscientious is necessary or rewarding, this trait may become central to their personality, even if their genetic inheritance may have inclined them towards carelessness. The sooner such environmental influences are felt, the more impact they have, because young brains are more easily changed than old ones. Indeed, nurture starts to have effects on personality even before birth.

An unborn child may have genes which would normally incline them to be serene and laid back, but if the mother happens to be under great stress during pregnancy the cortisol in her blood can pass to the foetus' brain and stimulate neurons in the developing amygdala – the brain nucleus which generates emotions. The resultant 'dancing' of amygdaloid neurons during gestation could strengthen the pathways carrying signals from the amygdala, and prime the child to be fearful for the rest of her life.



Exposure to slightly different environmental stimuli in the womb means that from an early age the brains of identical twins develop in different ways

This mechanism is how identical twins can have entirely different personalities. There are no single genes 'for' personality traits, such as conscientiousness or extroversion, but variations in many genes work in concert to determine how much of these characteristics an individual is likely to manifest. Identical twins share gene variations, but as soon as they have split into two individuals they are subjected to slightly different environmental stimuli. Even being in different positions in the womb has an effect – one child may receive more or less hormones, for example, another may hear more of the outside world, or feel bumps on the mother's body more easily because he or she happens to be a little closer to the front. These apparently minute differences can have profound effects on developing brains, such that by the time the twins are born they may already be startlingly different. If you could see the surface of their brains beneath the skull you would be able to discern that the very shape of their wrinkles and bumps is different.

As they become toddlers the differences become more obvious. Outside the confines of the uterus an infinite variety of experiences are available, and the two infants will interact slightly differently with the

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A child's genes may incline them to be laid back but, if the mother is stressed during pregnancy, cortisol can pass to the foetus' brain

world at every eye-blink. The cumulative effect of these minuscule differences may be enormous.

Take for example, autism. The condition is now known to have a strong genetic component, but it does not necessarily develop in a child with an autism-prone genome. Tiny environmental influences – too random and minute for anyone to predict or control – can offset genetic inheritance. Hence, there is about a one in three chance that, though one twin is autistic, their identical brother or sister is not.

Epigenetic factors

Things get more complicated as the children grow up. As their experiences become ever-more diverse, the once-identical DNA in the twins' cells starts to differ. The actual genes remain the same, but differences in environmental factors, such as illness, traumatic experience or exposure to toxins causes chemical changes to take place in and around the DNA thread – so-called 'epigenetic changes' – which alter the way that the genes are activated or 'expressed'. Hence, by adulthood the twins are effectively different genetically. Although they may still exhibit many similarities in character, their personalities will necessarily be different, because they will have developed physically different brains.

Self-transformation

As well as genetic fortune and random environmental influences, personality can be molded deliberately. Most people are unhappy with at least one aspect of their personality. A vast counselling and self-help industry has grown up for this purpose, ranging from rage control to assertiveness training, self-forgiveness to various types of therapy.

Although traditional methods of self-transformation are likely to be lengthy and difficult, it seems they can work. In one study researchers found that participants were able to make significant personality changes within four months. For example, people who wanted to become more extroverted tested as being higher in extroversion by the end of the study period. Along with changes in how they responded to personality testing, they also reported significant changes in their daily behaviour, which matched the personality changes they wanted to make.

So, the long and short of it is, take no notice of those who claim 'you can only be yourself'. With effort, time and determination you can be more like the person you would like to be. ■

FREE WILL
THE GREATEST ILLUSION?

Neuroscientists peering into our brains are becoming ever more convinced that free will is an illusion, simply a creation of our mind that allows us a sense of control. SIMON CROMPTON delves into the science.

You were always going to start this article. It was theoretically predictable from the moment of the Big Bang. You were always going to [illegible] the inevitable result of everything that preceded it. Every bumping together of atoms and molecules, the [illegible] DNA, the precise combination of chemical and electrical signals that make you do what you do has been determined by the laws of science from the beginning of time.

That is what is known as determinism, and it cuts through traditional ideas of free will like a knife. In the past 30 years, discoveries in neuroscience have freshly stoked the fires of debate about determinism [illegible] free will [illegible] crackling among scientists, philosophers and religious figures since at least the days of Socrates. And determinism, most famously advocated by Isaac Newton, currently seems to be gaining the upper hand.

The reason for this is a sequence of brain experiments stretching back to the 1980s, which have indicated with increasing authority that our brains make decisions before we even become aware of them. Scientists today can

wire you up to a computer and predict what choice you are going to make many seconds before you believe you make it. If we're not conscious of our decision-making, how can we be said to be acting voluntarily, to be 'willing' our every deed? And if we're acting consciously, exactly what is determining what we do?

Scientific inquiry, it seems, is killing the very idea of free will. Or is it?

Brain activity started, on average, 300 milliseconds before subjects were conscious of making the decision

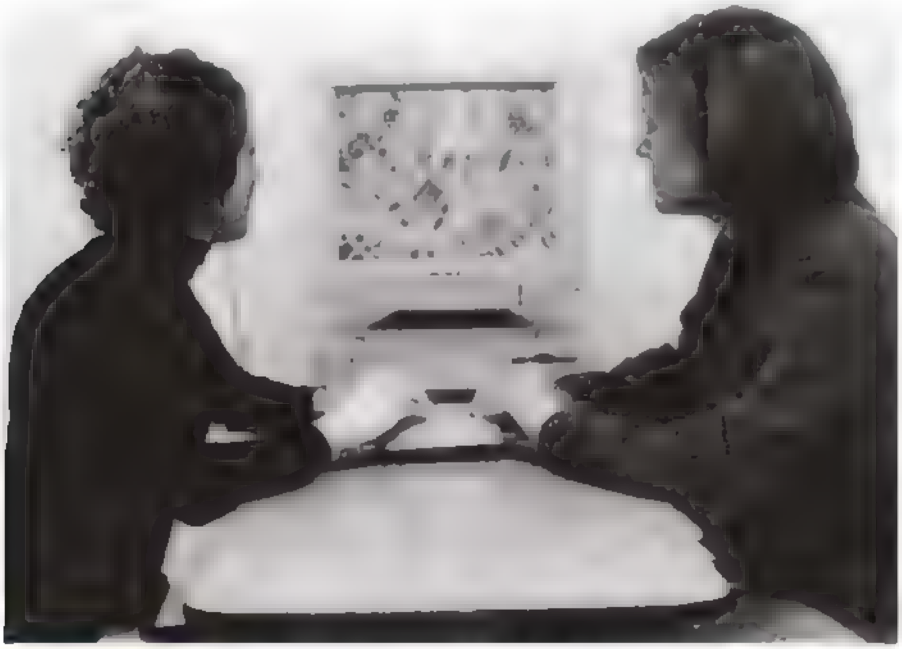
Decisions, decisions

Imagine looking at a clock on a computer with a rapidly rotating hand, and being asked to push a button at any point decided by yourself. You have to note the position of the hand on the clock face at the moment you decide to move your finger. All the while, your brain's electrical activity is monitored using an electroencephalogram (EEG).

This was the experiment carried out by American neurologist Benjamin Libet in 1983, which caused a free will re-think. Libet calculated participants' precise conscious decision time, using the times they noted as their decision time and the time the button was actually pushed. Then he compared this decision time with a surge of brain activity that earlier research had shown indicated decision-making. He found that the brain activity started, on average, 300 milliseconds before subjects were conscious of making the decision. This change in brain activity that precedes conscious decisions, called readiness potential, has been deemed a blow to free will, suggesting that the brain prepares to do something well before we 'decide' to do it.

Libet's experiments were simple, but his findings have been elaborated on by his followers. In 2010, neurosurgeons and neuroscientists from UCLA and Harvard repeated Libet's experiment, this time inserting electrodes into the brain to record activity from individual neurons. They detected readiness potential up to 1.5 seconds before a decision.

What's more, in 2007, brain-scanning research by Berlin-based neuroscientist Professor John-Dylan Haynes showed that some decisions we make can be predicted up to seven seconds in advance. He placed study participants into a brain scanner and asked them to push a button to their left or right side – whichever they wanted, whenever they wanted. The patterns of brain activity leading up to 'right' decisions were found to be different from 'left' decisions, and became clear seconds in advance of the button being pushed.



REVERSE SEANCE In Wegner's famous experiment, volunteers believed they were controlling the movement of a cursor on a screen – even though their input actually had no effect whatsoever on the cursor's movement

Self-delusion

Perhaps most controversial are the experiments and views of American psychologist Professor Daniel Wegner who, before his death in 2013, argued that our sense of control over what we do is self-delusion. He pointed out that there were constant examples of us being mistaken about being the authors of our own actions.

Sometimes we do things but don't think we're doing them: for example, moving a glass around a ouija board, twitching a stick when divining water, or accomplishing tasks under hypnosis. On the other hand, sometimes we aren't doing anything when we think we are. Prof. Wegner demonstrated this with a kind of reverse seance. He fixed a small board on top of a computer joystick, and asked two participants to sit on either side with their fingers on the →

D WEGNER, T WHEATLEY

A volunteer undergoes an EEG during an experiment at The University of Melbourne's Decision Neuroscience Laboratory

UNIVERSITY OF MELBOURNE

SOLVING THE MYSTERY Some neuroscientists and psychologists believe that seemingly inexplicable coincidences experienced with ouija boards could simply be unconscious actions carried out by participants

ON TEST In Professor Haggard's lab, muscle activity in the hand is measured as part of an experiment to determine if free will exists or not

DUALIST IDEA 17th-century philosopher René Descartes believed that the soul or mind could exist separately from the brain and body. But this is now disputed by science

STOCKPHOTO / MARTIN POPE CAMERA PRESS / GETTY IMAGES

board, causing a cursor to roam over pictures on a screen. They were told to stop the cursor whenever they liked. After the cursor stopped, the participants were asked how strongly they felt that they, individually, had chosen the stopping place. Invariably, participants believed they had controlled the landing place. The trick was that one of the two participants was, in fact, an experiment coordinator who had complete control of the cursor all the time. The movements of the true test subject didn't control the cursor at all.

In other words, said Prof. Wegner, we fool ourselves constantly and have what he called "the illusion of conscious will".

This has led to other psychologists and neuroscientists taking the idea further, saying that the feeling of intention is something humans always attribute to their actions after the fact. We make up stories so that we can take ownership of actions that would have happened anyway.

Even for the most pragmatic of scientists, this sounds like a troubling vision of humans as programmed automata, our deeds the products of unconscious processes rather than thought. But that is by no means the whole story.

We make up stories so that we can take ownership of actions that would have happened anyway

The great debate

If science has taken debates about free will beyond the traditional arenas of 'independent' action, the new understanding it has brought about human consciousness is revealing the inadequacies of talking about 'free will' in the first place. As a result, scientists and philosophers alike are now engaged in framing new ways of looking at what it might actually mean to be 'free'.

Professor Patrick Haggard is a British neuroscientist who has collaborated with Libet and examines issues of free will and voluntary action at the Institute of Cognitive Neuroscience, University College London. Until recently characterised as 'anti-free will', he acknowledges his views have evolved as traditional debates seem increasingly irrelevant. One thing is clear, says Prof. Haggard: a scientific outlook can no longer accommodate dualist ideas – the belief held by religions and philosophers, such as René Descartes, that a soul or mind can exist separately from the brain and body.

"A neuroscientist has to believe that all our thoughts, feelings and experiences are the result of electrical and chemical events in the brain," says Prof. Haggard. That throws out of the window the idea that there is an 'I' telling the brain what to do.

But at the same time, he believes the idea that we simply deceive ourselves into believing we have conscious will is going too far. He points to recent work by Dr. Aaron Schurger in France, which has brought into question whether the readiness potential that Libet identified in the brain actually represents the brain planning what to do next. For some people it has brought free will back into the neurological picture.

Dr. Schurger developed earlier research indicating that when we make a decision based on, say, visual input, groups of brain cells start assembling evidence in favour of various outcomes. When this neural noise rises to a peak, it crosses a threshold and tips into a conclusion. Dr. Schurger proposed that this constant neural noise is involved in all decision-making. He created a computer model of electrical activity as the brain assembled information, and found it looked similar to the patterns of Libet's readiness potential. He argued that what looked like a pre-conscious decision-making process might indicate a readiness to make a conscious decision, rather than the decision itself. In an experiment, he showed that participants who had built up the most neural noise were quickest in making 'spontaneous' choices.

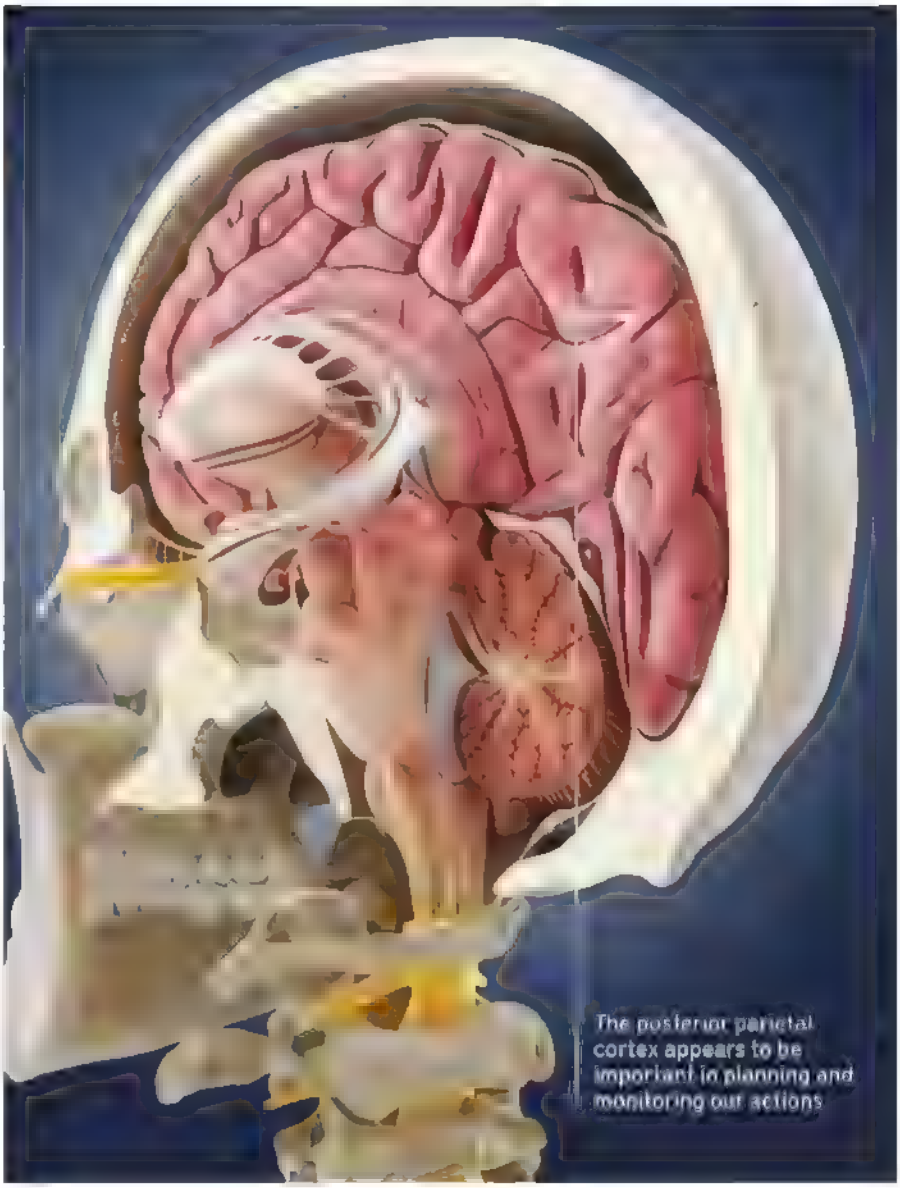
"Dr. Schurger is interesting," says Prof. Haggard. "You could say that his theory is compatible with free will because this crossing of the threshold is the decision to act, but I think he's rightly cautious about whether the process is conscious."

Conscious actions

Indeed, it is the big question of consciousness that needs to be addressed, because questions of free will are irrelevant without understanding it better. "I do think we have a conscious experience of what we are about to do," says Prof. Haggard. "But it's for others to decide whether that is free will. It's this stream of experience that our research is concentrating on. We need to know if there's a difference between conscious actions – such as making a cup of tea – and those you can do unconsciously, like walking. That will help us understand how consciousness affects our control of our actions."

Neuroscientists are looking at two areas of the brain that seem to give us →

a sense of control over what we're doing. The posterior parietal cortex at the back of the brain seems to have a role in planning and monitoring our actions. And the fronto-median cortex, where the two hemispheres meet, is active before movement. When doctors stimulate this area with electricity, patients have reported feeling the urge to move their arm. "That sounds a little bit like 'will'," says Prof. Haggard.



The posterior parietal cortex appears to be important in planning and monitoring our actions

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The broader picture

Philosophers are also accommodating advancing neuroscience into their enduring debates about free will. The fact is, says Helen Beebee, Professor of Philosophy at Manchester University, that what neuroscientists are saying hasn't come as a particular surprise to many.

"There's a great philosophical tradition, one which I am part of, which says that even if everything we do has a cause that can fully explain that it is going to happen, it's still perfectly possible to act freely. Before Libet, most of us thought there were prior causes anyway – we just didn't know what they were."

Beebee believes that a rounded look at human experience reveals that neuroscience is only part of the picture. "Say, for example, you looked at the last million years on a purely molecular level: you wouldn't see evolutionary processes, or animal behaviour. You'd have your story of how one thing led to another in terms of physics and chemistry, but you'd have missed out on some other very important stuff."

"If you look at the brain as a neurological machine, of course you're not going to find free will there, because it's not the level of description at which free will crops up," continues Prof. Beebee. "Why do we require determinism to be false to have control over our lives? None of us feel we have a gun to our head, are being coerced into making our cup of tea, or are in the grip of some hypnotic, zombie-like state."

> Philosophers and neuroscientists alike know that we are not robots, emptily fulfilling pre-ordained roles

The real lesson from recent research on human consciousness and decision-making is that philosophers and neuroscientists alike know that we are not robots, emptily fulfilling pre-ordained roles. We know that to accommodate the infinitely rich experience of being human, the brain has infinitely complex processes, and that current research is only scratching the surface of the simplest of these. Deciding whether to push a button is one thing, deciding whether to marry someone is another thing entirely. The case against free will is definitely not proven. ■

GREAT MINDS

[illegible]

STEVEN PINKER PSYCHOLOGIST Speaking in 2011 youtu.be/VQxJI0COTBo

[illegible] will in the [illegible] of a spiritual soul. Behaviour is the product of physical processes in the brain. But when you have a brain co[illegible] 100 billion neurons connected by [illegible] trillion synapses there's a vast amount of complexity, so human choices will not be predictable in any simple way from a given set of stimuli. We also know that the brain is set up so that there are at least two kinds of behaviour: choosing how to move a chess piece is different from your iris closing if I shine a light in your eye. It's that kind of behaviour, that has a mental model of the world which can predict the consequences of certain behaviours, that carves out the realm of behaviour that we call free will.

DANIEL DENNETT PHILOSOPHER Speaking in 2014 youtu.be/joCOWaaTj4A

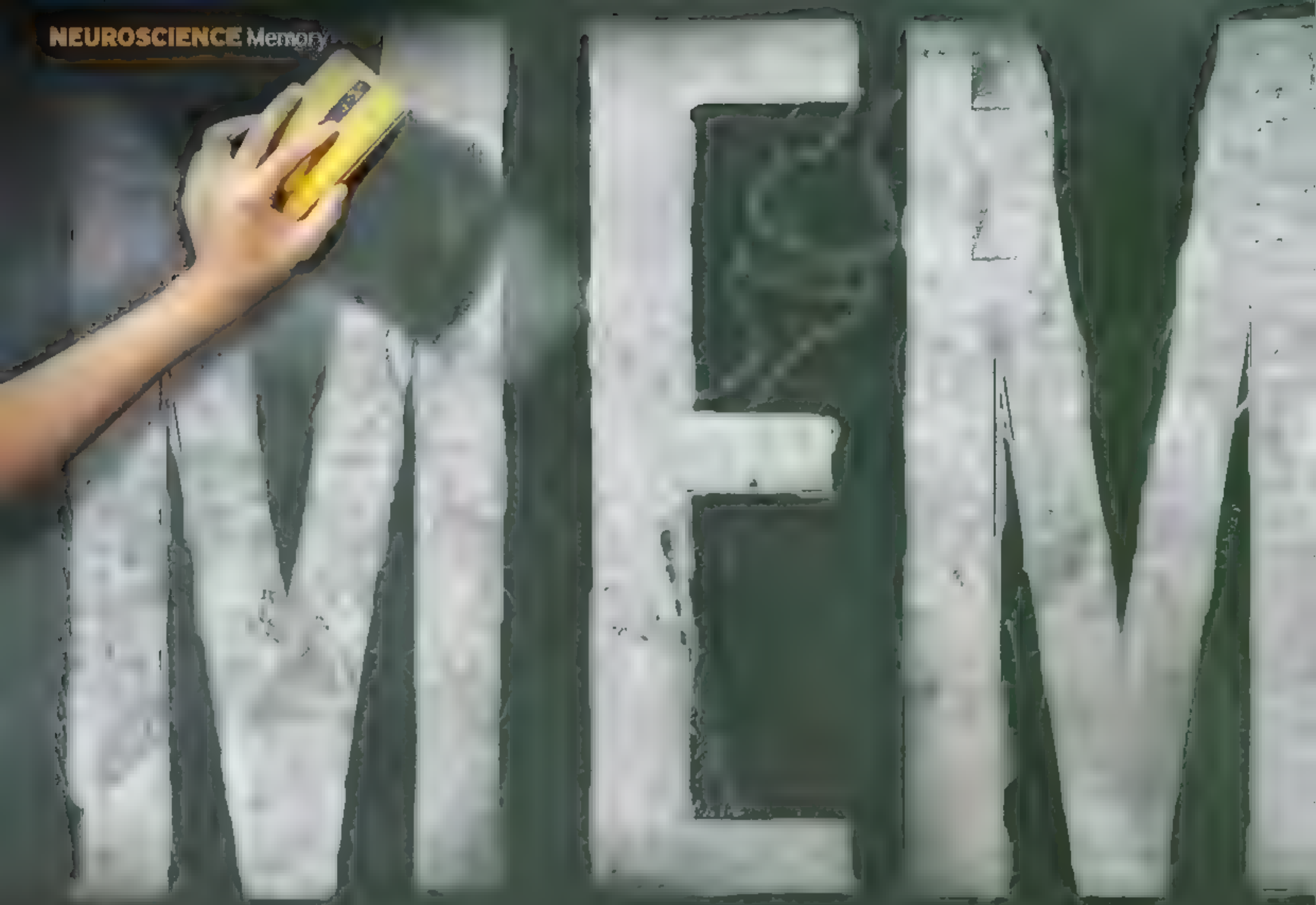
Free will is our capacity to see probable futures in time to take steps so that something else happens instead. What happens is determined, but it isn't as important as people have thought [illegible] doesn't imply inevitability. We have to recognise that there are varieties of free will. The traditional varieties – who cares i[illegible] the varieties worth wanting, are perfectly compatible with determinism. Do we have to give up something? Yes, we have to give up some of our ideas and ideology about [illegible] will scare some people, who want to be absolutist about responsibility. The idea of "in the eyes of God, that's a sin"... that has to go. What we replace it with is still a very rich and familiar concept, and that is: we are not deluded about our own capacity. We are determined to be masters of our fate, to a surprising and gratifying degree.

JIM AL-KHALILI PHYSICIST Writing in 2013 bit.ly/1aNFooC

Do we have free will? Yes, I believe we still do. It doesn't matter that we live in a deterministic universe in which the future is, in principle, fixed. That future is only knowable if we were able [illegible] whole of space and time from the outside. But for us and our consciousnesses embedded within space-time, that future is never knowable. It is that very unpredictability that gives us an open future. The choices we make [illegible] real choices, and because of the butterfly effect, tiny changes brought about by our different decisions can lead to very different outcomes and different futures. So, thanks to chaos theory, our future [illegible] knowable to us. You might prefer to say that the future is preordained and that our free will is just an illusion but our actions still determine which of the infinite number of possible futures gets played out.

MARC PAUL PSYCHOLOGICAL MAGICIAN www.marcpaul.com

Magicians and mind-readers have lo[illegible] known that free will is an illusion. In fact we've been using that know[illegible] our advantage for centuries. Any good performer can create the perfect illusion of free choice and yet secretly manipulate events [illegible] that the choice is anything other than free. It's fascinating to me that neuroscientists are only now discovering the science behind why th[illegible] Choices only feel free [illegible] psychological principle called cognitive dissonance. Good performers use this to give an audience the feeling that they've made decisions for themselves, but in some tricks these choices are largely irrelevant as the performer has already decided on the outcome or knows what choices are likely to be made. An audience will swear they've exercised free will, and [illegible] for us magicians.



What if you could wipe out a hurtful moment from your past, implant a new memory or easily remember everything for an exam? **NICOLA DAVIES** looks at how science will soon be able to shape your memories

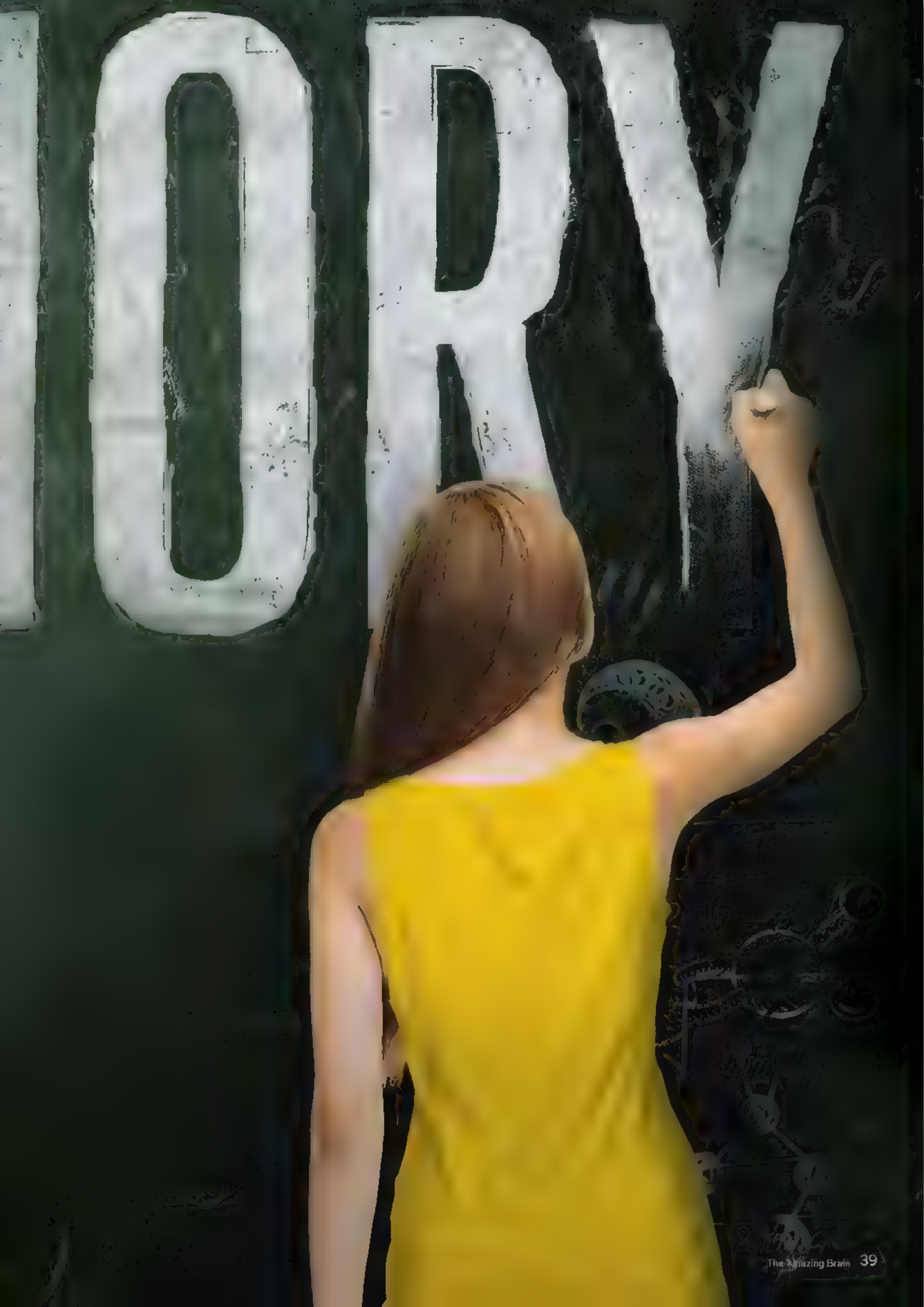
Ever wished you had a better memory so you were able to recall names, dates and faces more easily, or even get better grades in exams? How about removing all recollection of a failed relationship like the characters in Michel Gondry's Academy award-winning movie *Eternal Sunshine Of The Spotless Mind*? Or virtually travelling the Solar System via false memories implanted directly in your mind like Arnold Schwarzenegger's Douglas Quaid in the sci-fi classic *Total Recall*?

Well, therapies like these may be coming sooner than you think as scientists have been making great strides in how to delete, improve and even create memories.

"Memory is a very important aspect of cognition," says Dr. David Vauzour, a research fellow at the University of East Anglia. "It refers to what you can remember along with the capacity for remembering. Some memories are retained for a short period of time and then discarded but the most important ones are stored in the brain and can be retrieved at will. This process of learning new information, storage and recall involves a complex interplay of brain functions."

It is this complex network of nerves and chemical processes that must first be unravelled to help shed light on how the human brain stores and recalls memories, before we are eventually able to figure out exactly how to manipulate them. →

ILLUSTRATION: SHUTTERSTOCK; EPDESIGNS.CO.UK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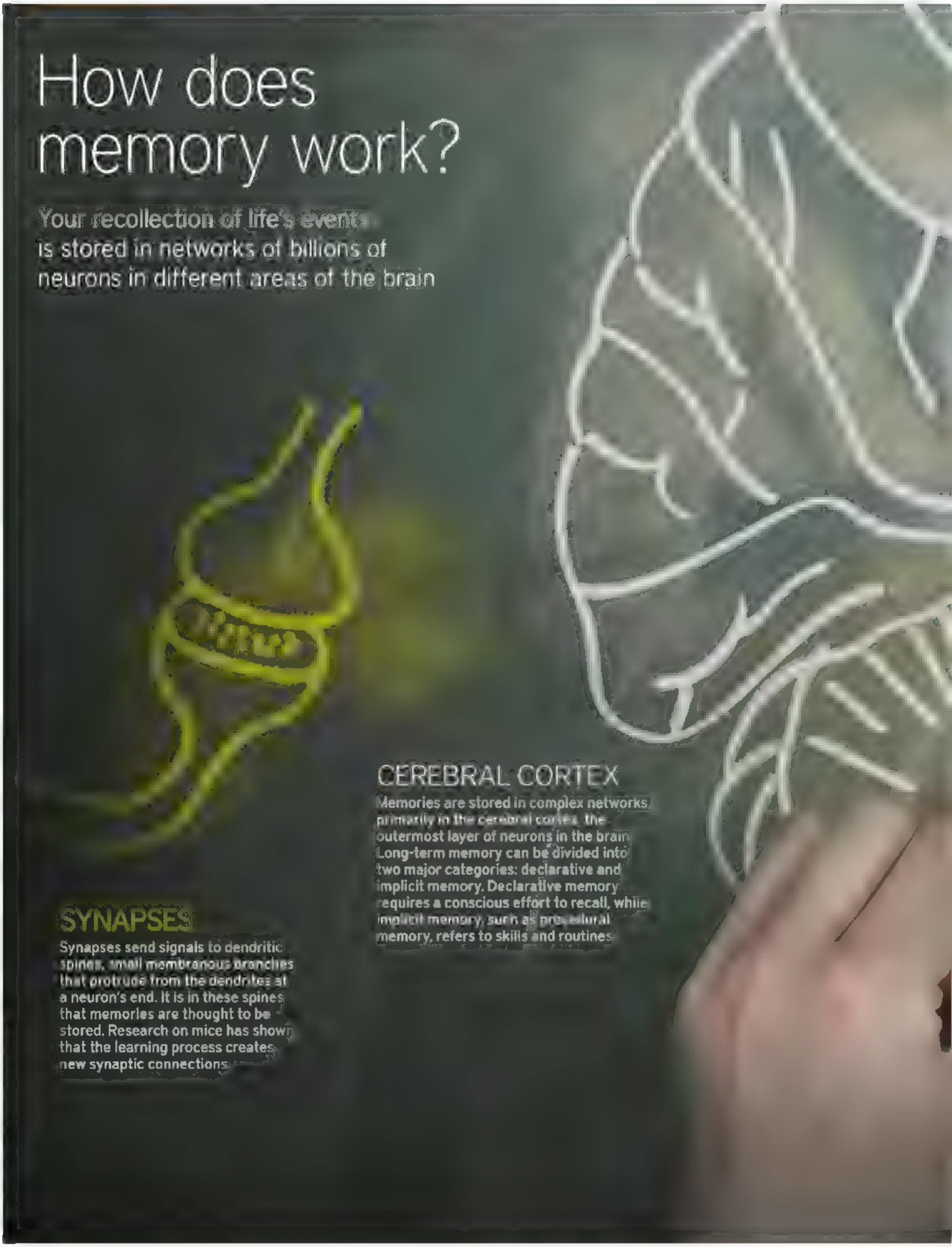


How does memory work?

Your recollection of life's events is stored in networks of billions of neurons in different areas of the brain

CEREBRAL CORTEX

Memories are stored in complex networks, primarily in the cerebral cortex, the outermost layer of neurons in the brain. Long-term memory can be divided into two major categories: declarative and implicit memory. Declarative memory requires a conscious effort to recall, while implicit memory, such as procedural memory, refers to skills and routines

SYNAPSES

Synapses send signals to dendritic spines, small membranous branches that protrude from the dendrites at a neuron's end. It is in these spines that memories are thought to be stored. Research on mice has shown that the learning process creates new synaptic connections

ILLUSTRATION: CHRISSTOCKERDESIGN.CO.UK

The two walnut-shaped amygdalae are clusters of neurons that deal with emotion and fear. In a 2013 study led by Haohong Li and Mario Penzo and published in *Nature Neuroscience*, the specific part of the central amygdalae that encodes fear memory has been pinpointed – it's called the lateral subdivision

HIPPOCAMPUS

Crucial to both spatial awareness and memory, we have one hippocampus on each side of the brain. "Long-term memories are likely formed by a variety of different mechanisms depending on the type of memory," says Dr. Michael Yassa of the University of California. "There is evidence supporting the notion that long-term memories for facts and events are stored initially using the hippocampus, but eventually most memories become stored as a distributed representation throughout the brain. The process is likely some form of strengthening of communication among neurons."

Involved in consolidating memories, in particular spatial memory, the entorhinal cortex acts as a gateway between the memory-forming hippocampus and neocortex, which deals with sensory perception

Deleting memories

While memories can be a source of great pleasure, they can also be a source of great pain. So imagine being able to get rid of them

Sufferers of conditions, such as post-traumatic stress disorder (PTSD) or drug addiction, know all too well the painful effects of memory. In these cases, memory deletion may be the answer. People with PTSD constantly relive traumatic memories. Similarly, drug addicts connect certain habits with a previous sensation of being high, which stimulates their craving. By removing specific memories, traumatic emotions and harmful behaviours can be prevented.

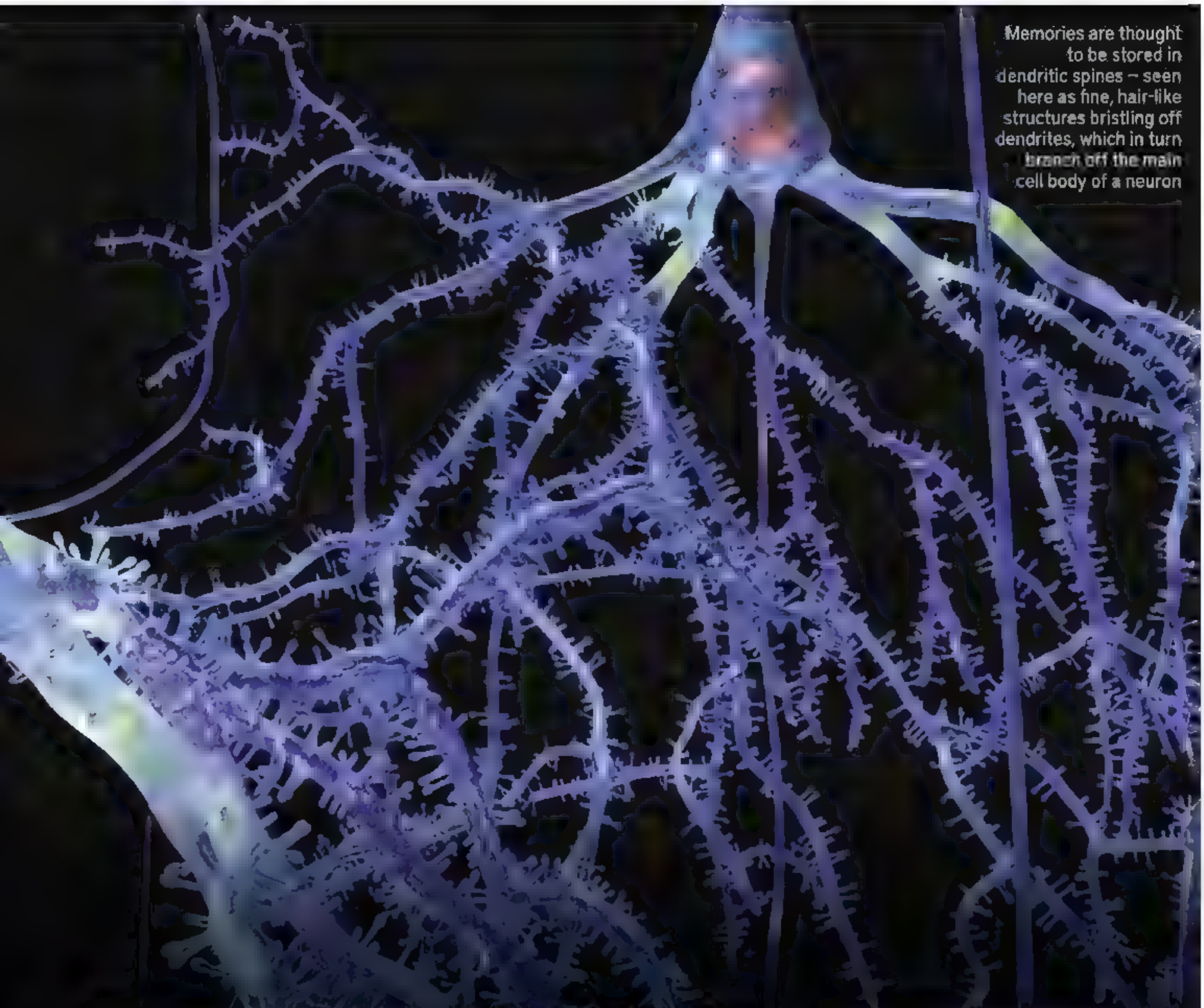
So, how exactly can memories be deleted? "Researchers have used a three-stage model to describe how the brain learns and remembers, with impairment in any of these processes resulting in memory failure: acquisition, consolidation and retrieval," says Dr. Vauzour, a research fellow at the University of East Anglia.

One study taking advantage of the consolidation process was a "within-subjects manipulation" study, which was conducted by Marijn Kroes and colleagues at Raboud University Nijmegen in the Netherlands. Memories are periodically rewritten in the mind or reconsolidated, somewhat like defragmenting a hard drive. But Electroconvulsive therapy (ECT) appears to prevent memories from being rewritten, or alters them during the reconsolidation process. In the team's 2013 study, published in *Nature Neuroscience*, participants undergoing ECT for depression were shown a troubling story in words and pictures. A week later they were reminded about it and given ECT. This completely wiped out their recall of the distressing narrative.

Chemical cut

Similar breakthroughs have also been found taking the chemical approach. A 2013 study, led by Dr. Courtney Miller of the Scripps Research Institute in San Diego, sought to help methamphetamine addicts by targeting the removal of memories linked with drug use.

"What makes this finding so exciting is that the inhibitors seem to be incredibly selective as to the memory type," says Dr. Miller. "We think we're able to selectively target drug-associated memories, and hopefully traumatic memories in the



Memories are thought to be stored in dendritic spines – seen here as fine, hair-like structures bristling off dendrites, which in turn branch off the main cell body of a neuron

future, because the brain is using a different mechanism to store them."

Meanwhile, more recent research published in *Cell* in January 2014, reveals that drugs known as histone deacetylase inhibitors (HDACIs) can enhance the brain's ability to permanently replace old traumatic memories with new memories.

In the first phase of the study, carried out at the Massachusetts Institute of Technology (MIT), mice were exposed to a tone followed by an electrical shock. Once the mice learned to associate these two events, they began to freeze in fear upon hearing the tone, even when they did not receive a shock. The researchers then repeatedly presented the tone without the shock to test whether the mice could unlearn the association and stop freezing in response to the tone. This was successful for mice exposed to the tone-shock pairing one day earlier, but not for mice that formed the traumatic memory one month earlier. These mice were then given HDACIs before undergoing the 'unlearning' exercise. The mice then stopped freezing in response.

Electroconvulsive therapy appears to prevent memories from being rewritten, or alters them

Delving deeper, the researchers from MIT have discovered a gene essential for 'memory extinction', called TET1. Published in *Neuron* in 2013, findings show how boosting TET1 activity might benefit post-traumatic stress disorder sufferers by making it easier to replace fearful memories with positive ones. Researchers had two sets of mice develop a fear of a cage by electrocuting them there. The mice were then put into a cage without being electrocuted. Those with an inhibited TET1 gene no longer feared the cage, because the fear memory was replaced with the new memory of not being electrocuted.

Memory boost

Scientists are discovering new ways of implanting memories and improving our ability to recall events and facts

In the Leonardo DiCaprio film *Inception*, professional criminals use an experimental military technology to implant ideas and memories into a victim's mind while they sleep. The concept may seem about as far-fetched as a movie premise can be, but in reality, false memory implantations happen all the time – including when people are awake. What's more they can have drastic consequences, especially in the case of court trials where juries place a disproportionate amount of credibility on eyewitness testimony.

Every one of us is susceptible to false memories, even those with otherwise exceptional powers of recall. This was shown in a 2013 study led by Lawrence Patihis, then at the University of California, Irvine, now an Associate Professor at The University of Southern Mississippi. Patihis compared 38 'control' individuals with 20 individuals with highly superior autobiographical memory – in other words, the ability to remember personal experiences as well as more general facts and knowledge. Despite it being likely that the latter group might be immune to memory distortions, the opposite was found. Over a two-week period, a series of exercises designed to test participants' susceptibility to forming false memories were administered. In each case, false memories were apparent just as often in those with superior memory as in controls. For example, when presented with a word list that included 'thread', 'knitting' and 'pin', both groups were likely to later 'remember' also having seen 'needle', which was never shown.

More recently, Nobel Prize winner Susumu Tonegawa was able to successfully implant fear memories in mice. Tonegawa and his team genetically engineered mice to express Channelrhodopsin-2 (ChR2) – a protein in neurons associated with memory formation and storage in the hippocampus (see page 45).

Improving memory

Kim Peek, the 'megasavant' who was the inspiration for the four-time Oscar winning film *Rain Man*, could remember almost everything he had ever read. He could also read both pages of a book simultaneously and retain the information. While we would all love to be like Kim Peek, there are several effective ways of improving your memory.

"Physical health, emotional state, stress level and diet exert a big influence on how well you learn and remember," explains Dr. David Vauzour, a research fellow at the University of East Anglia.

One study at the University of Alabama, published in the *Journal of Neurology* in 2013, revealed that those who more strictly adhered to a Mediterranean diet were less likely to develop problems with their memory. In another study, led by Associate Professor Yves Sauvé of the University of Alberta, Canada, it was shown that high levels of Omega-3 in a person's diet can help to improve the communication of the neurons used for memory.

Evidence suggests that exercise is also key to a healthy memory. Research led by Dr. Sandra Chapman of the University of Texas at Dallas in 2013, showed that aerobic exercise improves memory by helping maintain consistent and healthy blood flow to the hippocampus.

There are some people, however, who balk at the thought of putting [illegible] the pavement, and would instead prefer to simply swallow a memory-improving tablet. This attitude has led some students wishing to stay alert and retain memory during exams to turn to so-called 'smart drugs'. Modafinil, Ritalin and Adderall are frequently sold on the black market. But since these are prescription medications for conditions that most students do not suffer from, such as narcolepsy and ADHD, the long-term effects are unknown and potentially dangerous.

Moreover, they may not even have the expected effect of improving memory. Although they can give the user the impression of a temporary memory boost, a placebo-controlled trial, led by Irena Ilieva, when she was at the University of Pennsylvania, showed no improvement in the performance of young adults taking Adderall compared to those taking a placebo. So it would appear that there are no quick-and-easy shortcuts to improving memory with pills. ■

Since 'smart drugs' are prescription medications, the long-term effects are unknown and potentially dangerous

The 'megasavant' Kim Peek was able to memorise everything he ever read

Give your neurons a boost by eating high levels of Omega-3, as found in foods such as mussels

Fear factor

1 A mouse was put in an environment (blue box) and the neurons responsible for memorising the environment were labelled. These cells were made responsive to light.

2 The mouse was put in a different environment (red box) and light was delivered to the brain to activate the previously labelled cells, so it recalled the first box. Electric shocks were given

3 When the mouse was returned to the first environment, it showed signs of fear, revealing how it had formed a false fear of the first box, where it was never shocked.

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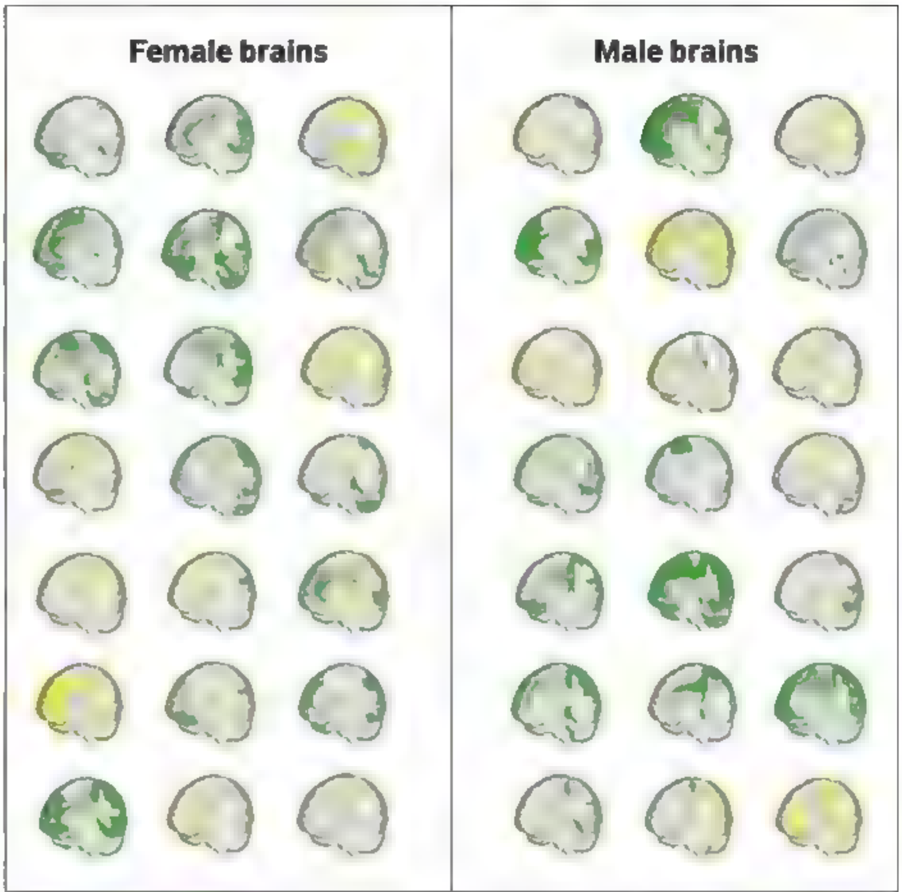
ARE MEN FROM MARS AND WOMEN FROM VENUS?

The bestselling book *Men Are From Mars, Women Are From Venus* claims the sexes think completely differently, like we're from distinct planets. But is this really the case? Do disparities between male and female brains dictate behaviour? And should we stereotype the sexes? **CHRISTIAN JARRETT** investigates →



NOT SO DIFFERENT Scans from 42 adults, showing brain region volumes (green for large, yellow for small), highlighting how many features are common to both sexes, making it difficult to draw conclusions about differences in male and female brains

More than ever, people are looking to brain science to answer the perennial question of how men and women differ – and how they might better understand each other.

It's true there are some important differences between men's and women's brains, on average. On this, most of the world's experts agree. However, contrary to the impression you might get from the mainstream media, most of these neurological findings are not relevant – at least not yet – to explaining possible differences in men's and women's behaviour or mental abilities, such as men tending to outperform women on spatial tasks, or women usually showing superior performance on emotional recognition.

Some facts. If you were to hold a typical woman's brain in the palm of one hand, and a typical man's brain in your other, the most obvious thing you would notice is that the man's brain is bigger and heavier. A study from 2005 weighed the brains of 58 women and 42 men at postmortem, and they found that the women's brains averaged 2.8 pounds on average, compared with an average of over three pounds for the men. It's been estimated that this weight difference translates into women having fewer neurons on average in the cerebral cortex by about 16 per cent. Bear in mind that there is a lot of overlap in these statistics, so there are plenty of men who have smaller brains than women.

There are also some average sex-based differences in the size of individual brain structures – for example the amygdala, a brain structure involved in emotional processing, is usually larger in men. The insula, a structure associated with processing internal bodily states, is larger on the left side in men, but larger on the right side in women. Many studies have also reported that the hippocampus, a structure involved in memory, is larger in women. Although, last year, a study combining data from previous research on over 6,000 people, concluded that there are no sex-based differences in this part of the brain.

Another pertinent study, published in 2015, looked at scans of more than 1,400 men's and women's brains. It concluded that most people's brains have a 'mosaic' of structures – some with a more characteristically feminine form and some with a more characteristically masculine form.

"There's not one way to be male or female," says Professor Daphna Joel, who led the study at Tel Aviv University. "There are multiple ways. Most of these are overlapping."

Researchers argued this means that it is inappropriate to talk about 'male brains' and 'female brains' in the same binary way that we refer to male and female genitalia.

Bigger but not better

It's important to bear in mind that not only are the findings in this area constantly under revision and debate, but also that the behavioural and psychological implications of any observed sex differences is not always obvious. As a rule, bigger doesn't mean better when it comes to overall brain volume or individual brain structures. To take just one example, expertise in chess is associated with localised brain shrinkage, which is a sign of greater neural efficiency.

Experts like psychologist Cordelia Fine at the University of Melbourne,

ZOHAR BERMAN, DAPHNA JOEL


Gender stereotypes suggest that men are better at map reading

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in Australia, have also argued that many of the average brain-based differences between men and women are more likely to do with the issue of brain size rather than sex per se. Smaller brains, whether male or female, are built somewhat differently from bigger brains, and it just happens that women tend to have smaller brains, on average.

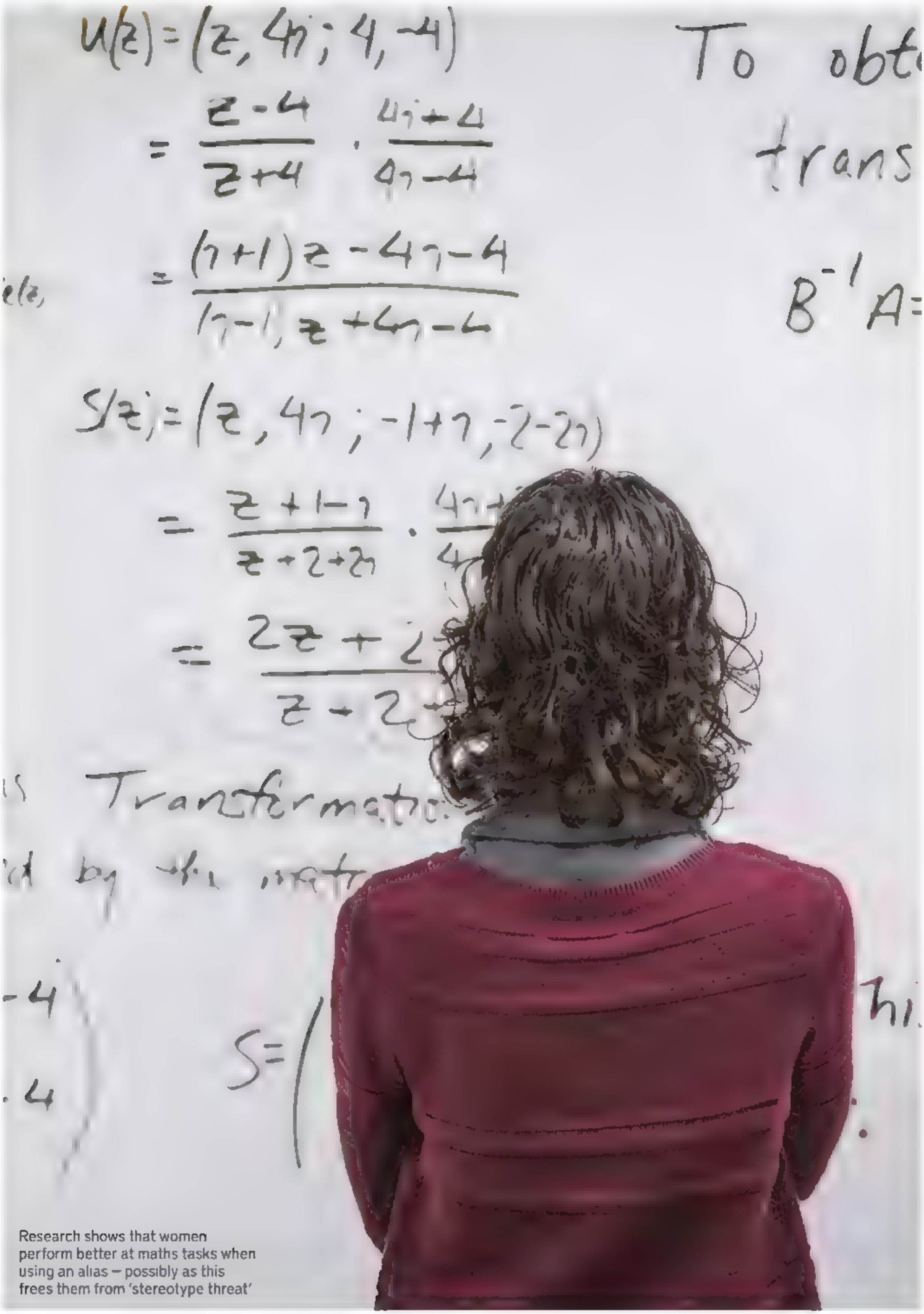
Another related theory, proposed by Geert de Vries, Director of the Neuroscience Institute at Georgia State University, states that average sex-based brain differences may be acting to compensate for other physiological sex differences, such as in hormones. Viewed this way, sex-linked brain differences contribute to the remarkable behavioural similarities between men and women, not their differences.

With these cautions at the back of our minds, it's important to recognise that some brain differences between the sexes are important because of their medical implications. For example, women's brains appear more adversely affected by brain injury, and more susceptible to developing Alzheimer's disease and to its effects on cognition. Whereas, men seem more inclined to develop Parkinson's, possibly because deep brain structures involved in motor control age more quickly in men than women.

Future research into sex-based brain differences could shed light on these issues, as well as the sex differences in vulnerability to psychiatric and neurodevelopment disorders. For example, the fact that autism and ADHD are far more prevalent in boys and men, while depression and anorexia are more prevalent in girls and women. In this context, some experts such as Larry Cahill at the University of California, Irvine, have raised concerns that so much medical brain research has been based exclusively on male animals, and they've argued that it's critical that female animals are tested too.

Unfortunately, the medical implications of any sex-linked brain →

It is inappropriate to talk about 'male brains' and 'female brains' in the same binary way that we refer to male and female genitalia



Research shows that women perform better at maths tasks when using an alias – possibly as this frees them from 'stereotype threat'

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differences tend to attract relatively little newspaper coverage. Instead, there's usually a lot more media interest and exaggeration when it comes to whether any postulated sex-based brain differences can explain, or even lend credence to, gender stereotypes about behaviour, such as the idea that women are better at being nurturing or that men are better at map reading.

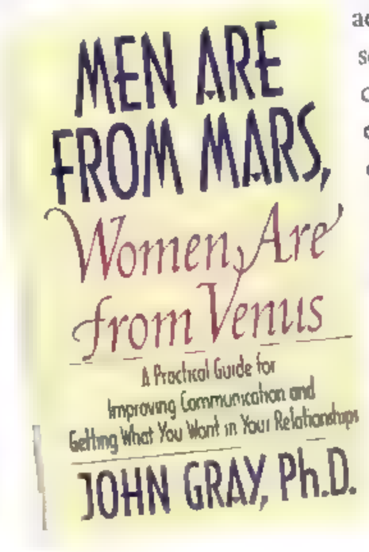
> It fuels unhelpful gender stereotypes that imply men or women are less suited to certain careers because of their brains

Sex stereotyping

In 2013, for example, neuroscientists at the University of Pennsylvania plotted the brain wiring patterns of 949 people and said they'd found that, from the age of 14, male brains tended to show more dense connections within each brain hemisphere, whereas women's brains showed more connectivity between the hemispheres. The researchers themselves speculated that this could help explain gender stereotypes, such as that women are better at doing two things at once. The logic was that multi-tasking is made possible by more cross-talk between the brain hemispheres – a mistaken idea re-hashed from John Gray's bestselling book *Men Are From Mars, Women Are From Venus*. Predictably, the media lapped this up, with headlines such as in the *Daily Mail*: "The connections that mean girls are made for multi-tasking."

It's sensible to treat these claims with some scepticism. The researchers didn't actually measure their participants' mental abilities, such as in multi-tasking or map reading, so they weren't able to link directly the brain wiring patterns they had found with behavioural differences in the sexes. Also, other experts looked at the data and they argued that the brain wiring differences between the sexes were incredibly subtle.

In 2015, the same University of Pennsylvania team followed up with another study in which they measured the connectivity patterns of hundreds more participants' brains, while they lay in a scanner, staring at a cross on a screen. The researchers focused on 264 functional 'nodes', or hubs (that is, regions in the brain believed to support distinct mental activities), finding that just six (2.3 per cent) showed a sex difference. They also looked at 36,716 specific functional connections in the participants' brains, finding that just 0.51 per cent showed a sex difference. The researchers argued again that these neurological differences might explain sex differences in cognition, but this time they acknowledged: "While sex differences in connectivity exist, on the whole, connectivity patterns of male and female brains are more alike than different."



John Gray's book has sold more than 50 million copies worldwide and spent 121 weeks on the bestseller list

Mythbusting

One issue when these kind of brain-based findings filter through to the mainstream media is that that they are interpreted by many commentators as providing evidence that any observed psychological differences between the sexes are somehow innate and immutable. Not only is this logic flawed – any neural difference between the sexes could just as likely reflect a cultural influence as an innate cause. But it potentially fuels unhelpful gender stereotypes that imply men or women are less suited to certain kinds of careers or pursuits because of their brains.

Indeed, there is research showing that when people are exposed to scientific arguments that say sex differences in behaviour or mental performance are fixed, this increases their belief that any gender inequalities in society are fair. The reality, as shown by many psychology studies, is that sex differences in behaviour are incredibly prone to social influence. For instance, women (but not men) perform better at maths tasks when using an alias. Presumably this is because this frees them from what's known as 'stereotype threat' – the fear that their performance will be used by others to support the stereotype that women are not as good at maths as men.

Sex differences in the brain should not be ignored. But neither should they be overstated and used to justify stereotypes. Overall, the research shows that men's and women's brains are more alike than different. As Cordelia Fine puts it in her book *Delusions of Gender*: "The male brain is like nothing in the world so much as a female brain." ■

ILLUSTRATION: ALEXANDER WELLS

WHY POWER CORRUPTS

Power affects the brain in the same way as winning a prize. **IAN ROBERTSON** reveals why having complete authority explains the behaviour of dictators

In his fifth anniversary as the world's youngest dictator, North Korean supreme leader Kim Jong-un's body is showing the strain. His recent limping reappearance, obese and diabetic, from a mysterious, month-long absence shows the physical toll his dictatorship is taking – but in what state is his mind?

Is he the "wild-eyed despot" *The Washington Post* describes him as? Or "dangerous, unpredictable, prone to violence and with delusions of grandeur" in the words of Kurt Campbell, former US Assistant Secretary of State for East Asian and Pacific Affairs? And was he always like that, or has the experience of dictatorship forged a Frankenstein?

The odd behaviour of dictators inclines us to see them as psychologically unbalanced individuals whose very mental instability may contribute to their mad, bad drive to dominate and oppress millions of people. A top secret psychological analysis of Adolf Hitler commissioned by the US Office of Strategic Services in 1943, for instance, alleged that Hitler had highly deviant sexual practices. These may have contributed to the fact that of the eight women with whom he had relationships in his life, three subsequently committed suicide and a further two attempted to.

Hitler's frothing, near-hysterical orations may have revealed a certain amount of deep inner turmoil, but they also contributed to a charisma that mesmerised millions of German

people. It was a spell-like effect that lived on for many years beyond his 1945 suicide.

Brutal to the bone?

While dictators can often behave oddly – the late Muammar Gaddafi's gaudy outfits and Kim Jong-un's startling haircut spring to mind – are they really the psychologically malformed monsters that the media likes to portray?

There are brutal dictators in whom there is no obvious sign of psychological disturbance. Syria's Bashar al-Assad, for instance, is a seemingly happily married family man. Al-Assad has a mild demeanour in keeping with his background as a successful, London-trained physician. Robert Mugabe of Zimbabwe is a very intelligent, highly religious man, but with no obvious evidence of inner trauma. Yet both these men have led brutal, atrocity-ridden regimes.

The same is true for Kim Jong-un, in spite of what *The Washington Post* and Kurt Campbell say about him. We know this because Kenji Fujimoto, the family's confidante and one-time sushi chef, was intimately involved with Kim Jong-il's inner circle and spent time with the North Korean heir as he grew up.

Kim Jong-un had a close relationship with his father – "that boy is like me" Kim Jong-il reportedly said – and he was adored by his mother. Unlike the narcissistic psychopath he is often portrayed to be, Kim Jong-un was capable of lasting friendships. This is according to flatmate João Micaelo, who was close to the North Korean over the

> Unlike the narcissistic psychopath he is often portrayed to be, Kim Jong-un was capable of lasting friendships

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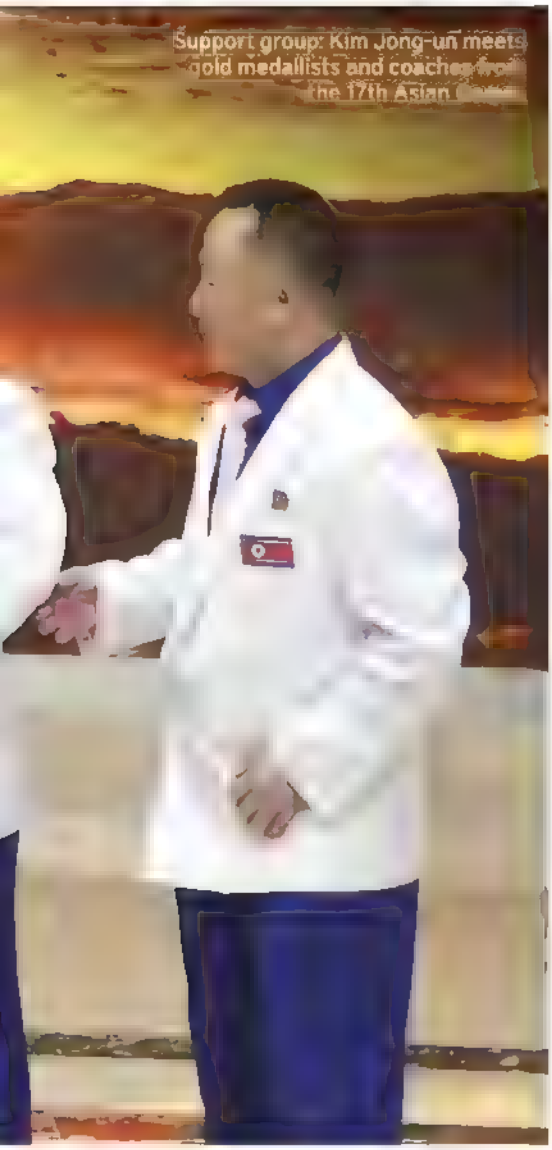

Support group: Kim Jong-un meets gold medallists and coaches from the 17th Asian Games

three years they were teenage schoolmates in Switzerland.

Micaelo describes Kim Jong-un as “a completely normal teenager”. Fujimoto recounts one occasion when, after an afternoon’s jet-skiing, the 18-year-old Kim Jong-un said dreamily and out of the blue: “We are here, playing basketball, riding horses, riding jet skis, having fun together. But what of the lives of the average people?” Psychopaths don’t have that sort of empathy.

Power trip

Kim Jong-un, then, is neither suffering from a long-standing narcissistic personality disorder nor is he a psychopath. This is in contrast to Joseph Stalin, for instance, whose

ILLUSTRATION: ALEXANDER WELLS

Five common traits of dictators

Are you unhappy in work? Does your manager make fun of you? It’s very possible that your boss has dictatorial tendencies. Check off their traits with our handy guide!

HOTLINE TO GOD

Success and power makes people feel special. Some believe that God plays a part in their greatness. Robert Mugabe announced that God helped with the constitutional changes that he introduced. Even democratically elected George W. Bush claimed that God spoke to him when making decisions. Bosses can succumb to the God Complex too.

LACK OF EMPATHY

Power inclines you to treat underlings as objects It focuses your attention on rewards and saps your ability to see things from other people’s points of view because, well – your point of view is right. People with even modest amounts of power take the credit for the work of underlings, and downplay their subordinates’ roles in doing the work.

HYPOCRISY

Power tends to make you a stickler for getting other people to follow rules and suffer sanctions, but lax in applying these to yourself. This comes from the feeling of ‘specialness’ that power creates because of its positive effects on mood. This continued anticipation of success can lead to making others follow petty rules.

BIG CHARACTER

Beware of a manager who likes to create emotional reactions in his underlings and subordinates. It needn’t just be fear, either. Even an apparently harmless joke at the expense of a junior colleague that causes a degree of embarrassment will do the trick as well. As can making staff grateful by some whimsical act of beneficence.

IGNORE CONSEQUENCES

Nothing quite unties the strings of restraint as a great amount of power. A God-like sense of invulnerability arises because power inhibits our sense of risk and also eliminates any tendencies for anxious worrying about the consequences of a particular action. Even tiny amounts of power make you more likely to take the last biscuit from the tin.

North Korea is the most militarised nation in the world. This parade of armed forces marked the country's 65th anniversary in 2013

PRESS ASSOCIATION

early criminality and fractured relationships with other people justify the label.

So, if pre-existing psychological disturbance cannot explain the behaviour of dictators, is there something about becoming one that causes them to carry out strange and appalling things? Yes there is, and the crucial ingredient is power.

Power is defined as having control over things that other people want, need or fear. Even tiny amounts of power can start to change us emotionally and cognitively. This is because power boosts the hormone testosterone in both men and women, which in turn increases activity of the key chemical messenger dopamine in the brain's 'feel good' centre, the so-called reward network.

> Power affects our mood through the same brain mechanisms that having sex or taking cocaine make us feel good

Power affects our mood through exactly the same brain mechanisms that winning a prize, being paid a compliment, having sex or taking cocaine make us feel good. Not only that, but the increase in dopamine can make us bolder, less anxious and even more smart. But there is also a dark side to power.

Like many neurotransmitters in the brain, dopamine operates in an 'inverted U' shape, with either too little or too much impairing the smooth operation of the brain. Through dopamine's cocaine-like disruption of the reward system, unfettered power can lead to serious problems of judgment, emotional functioning, self-awareness and inhibition. It also eliminates empathy and inclines you to treat others as objects, rather than as people.

In short, while Kim Jong-un may not have started out as a psychopath, as the years go on, unfettered power may make him one. ■

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THE EVOLUTION OF INTELLIGENCE

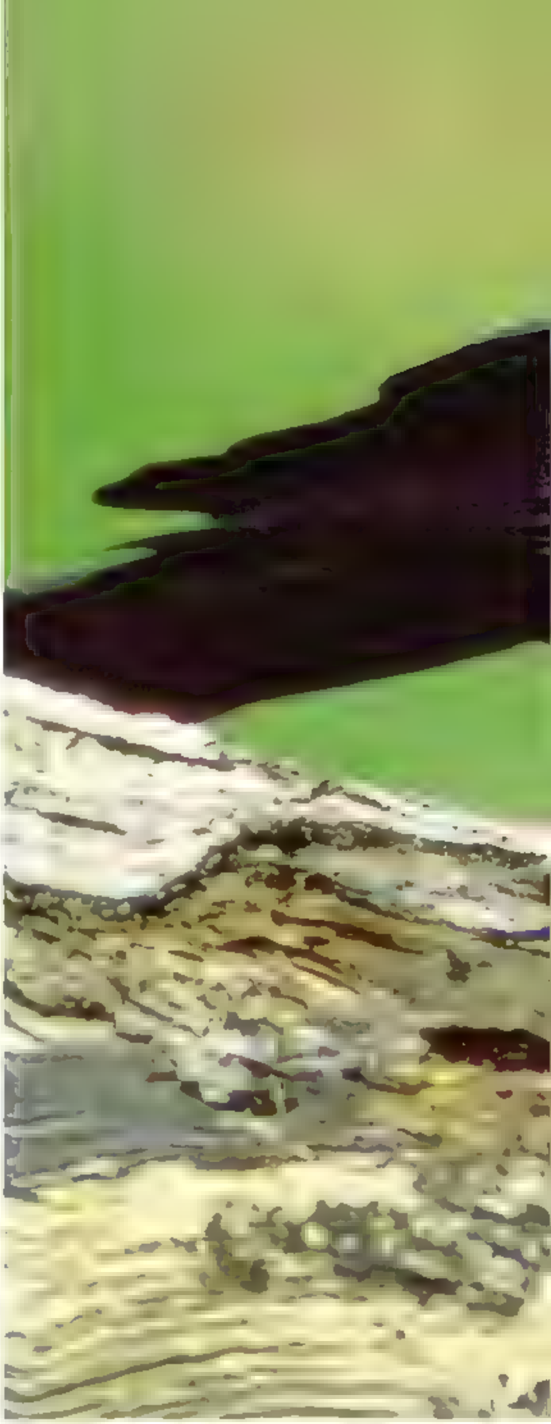
Why are some animals smarter than others? Are humans really the most intelligent species? **JV CHAMARY** explores how nature produces clever creatures with bigger, better brains

We humans put ourselves at the centre of the Universe. Throughout history, that outlook has biased our view of the natural world. So on a scale of intelligence in the animal kingdom, we might put our fellow primates at the top, followed by other mammals, such as elephants and dolphins. But over the past few decades, research has revealed some surprises, as illustrated by birds.

Being called 'bird brain' is an insult because our feathered friends are traditionally considered stupid, an assumption based on ignorance.

"We either don't know about what they do, or we're slightly focused on the type of species that actually aren't particularly smart," says Dr. Nathan Emery of Queen Mary University of London, and author of *Bird Brain: An Exploration of Avian Intelligence*. "If we were to choose a cow as our typical mammal, we may not think of mammals *per se* as being very smart."

Scientists don't agree on a definition for intelligence, so many say they study 'cognition', the ability to acquire and understand information. Cognition is the level of explanation between brain and behaviour. For example, if the electronics inside a TV are like brain circuits and movies are an animal's



> It's only the birds with the pilfering experience that adopt protective strategies. It takes a thief to know a thief
>
> *Dr. Nathan Emery, Queen Mary University of London*

observed behaviour, cognition would explain that TVs work by displaying a series of still images.

While some researchers equate intelligence with cognition, Dr. Emery thinks it is more specific: "Applying the cognitive tools that you have, but in a novel context, usually in terms of problem solving."

Dr. Emery trained as a primatologist and now focuses on the corvid or crow family, a group that includes ravens and jays. Corvids are arguably the cleverest birds: New Caledonian crows make tools from twigs and leaves to extract grubs from tree holes, for example, while Western scrub jays not only remember the location of hidden food, but also whether each cache contains perishable items. This means scrub jays have episodic memory – they can recall past events and plan for the future using 'mental time travel'.

With over 10,000 species of birds and 5,000 mammals, there's a huge range in intelligence, and the smartest species aren't distributed in the way you might expect. Just because we think humans are the world's smartest species, and we're closely related to chimpanzees, doesn't necessarily mean their mental abilities should be relatively close too.

So how do we recognise intelligence? One hallmark is 'theory of mind', the ability to imagine another individual's knowledge. Originally asked in chimps, studies by Dr. Emery and colleague Professor Nicola Clayton have found that corvids can also model the mind. If a scrub jay is hiding food and sees another individual, they'll return later to move their cache – unless the other bird is their mate.

When caching food, scrub jays understand what, where, when and even *who* is watching. This is influenced by what Dr. Emery calls 'experience projection' – the ability to create a mental simulation to predict potential outcomes. "It's only the birds with the pilfering experience, the ones that have been thieves in the past, that will adopt these protective strategies," he says. "It takes a thief to know a thief."

Scrub jays have episodic memory – they remember where they have hidden food

Is bigger better?

Birds illustrate that popular beliefs on intelligence are often false. For instance, people associate a big brain with a brilliant mind. But comparing species proves that can't be true: a sperm whale's brain weighs 8kg, over five times the mass of a human brain.

But while there's no relationship between cleverness and *absolute* size, there is a correlation with *relative* size. This is given by body weight versus brain volume, or by calculating an 'Encephalization Quotient', the ratio of observed to expected brain mass (from body size). Corvids have relatively large brains compared to pigeons, while ape brains are bigger than those of monkeys.

Structure is as important as size, a fact obscured by assuming humans are the pinnacle of nature. This belief stems from an outdated idea by Greek philosopher Aristotle, whose *scala naturae* or 'ladder of life' placed man on top.

The ladder influenced German neurologist Ludwig Edinger, who in the late 19th century proposed that

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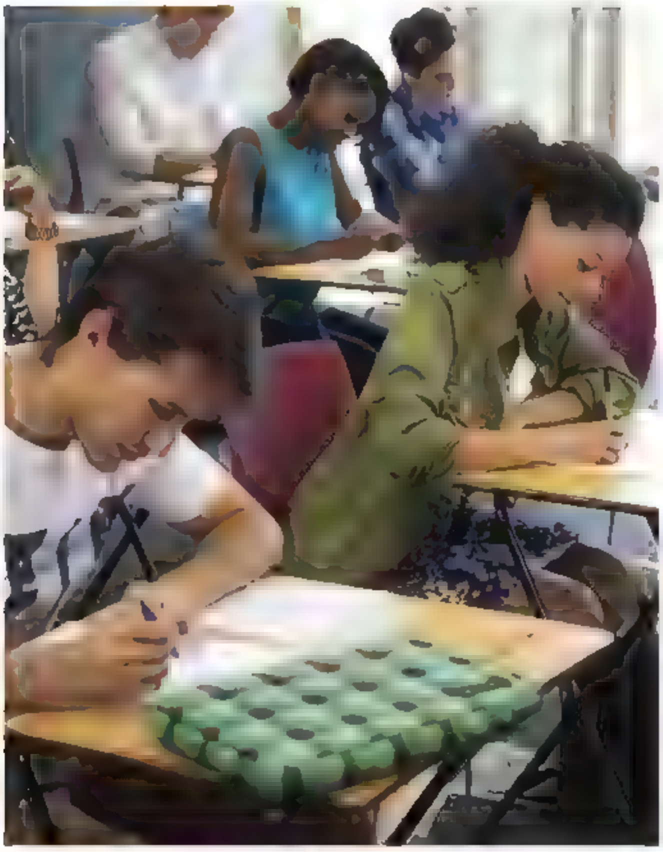
the vertebrate brain became increasingly sophisticated – and animals smarter – by adding new structures in a stepwise manner. Fish have an ancient 'paleostriatum' that controls instinctive behaviours, for example, and mammals have an extra 'neocortex' (Latin for 'new rind') – the grey matter that gives a brain its folded, walnut-like appearance. The neocortex is responsible for advanced cognitive skills like reasoning, so it was assumed vertebrates without a neocortex, like birds, weren't capable of intelligence.

Ever since Darwin, however, we've known that the process of evolution isn't a ladder – it creates diversity. This is best represented by a 'tree of life', with species on different branches independently adapted to their environments.

The evolutionary perspective inspired a large team of scientists, the Avian Brain Nomenclature Consortium, to examine existing evidence and carry out experiments on anatomy and genetics. Their results challenged the view that bird brains are simple. "We just said this view was completely wrong," says Dr. Erich Jarvis, a neurobiologist at Duke University in North Carolina, who led the consortium.

In fact, birds do have a cortex, or 'nidopallium' ('nested coat'). Unlike its folded mammalian counterpart, in which brain cells are arranged in six layers, the avian cortex consists of clusters. In mammals, the cortex resembles a club sandwich. In birds, the grey matter looks like pepperoni pizza. "It's clustered in the way the cells are organised, but it has similar neural network connections as the layered cortex does in humans," says Dr. Jarvis.

Mammals and birds shared a common ancestor over 300 million years ago, before the age of dinosaurs, which means that similar brain →



STROKE OF GENIUS An Intelligence Quotient (IQ) is a total score derived from one of several standardised tests that are designed to assess human intelligence

MENTAL GPS Research has shown that elephants store maps in their brains of the location for at least 17 individuals in their travelling herd

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GAME PLAY Living in groups creates competition between individuals, forcing them to work with and manipulate others in order to survive. The 'social brain' hypothesis claims that bigger brains evolved to understand social interactions within large groups

structures were created through 'convergent evolution', the result of common ecology, rather than ancestry. This occurs when separate branches on the tree of life find similar solutions to the same problem – in this case, packing cells into the skull. (Flight in bats and birds is the most famous example of convergence.)

Convergent evolution built the neural foundations for advanced mental skills. Dr. Jarvis studies language, another mark of intelligence, and believes the ability to imitate sounds – via speech or song – was made possible in both birds and people by duplicating the motor learning circuit, the network that controls muscle movements, to build vocal learning circuits. "This is what makes language more unique, or more specialised, in humans and several other species, like songbirds and parrots."

Mental skills

Even if a species has features like language or 'theory of mind', that doesn't necessarily mean they're intelligent. Not because the animal isn't smart, but because 'intelligence' itself is an artificial concept.

"Intelligence is the collection of things that we would call intelligent if humans did them," explains Professor Richard Byrne of the University of St. Andrews. "It's a kind of bag of abilities rather than a single, measurable quantity."

Humans have been trying to measure mental ability since the Victorian era, which led to the 'Intelligence Quotient'. IQ tests are a standardised way to assess people against their educational system, with 100 being average. That number doesn't equal brain power though. Just as you wouldn't say a brilliant mathematician is smarter than a musical genius, you cannot compare species.

The belief that humans are in some way extra special is also being eroded. Anthropologists see tools as a major step in technology, inspiring the idea of 'man the toolmaker'. But ever since Jane Goodall observed chimps making tools, naturalists are discovering more and more species that are also toolmakers, such as corvids.

We might not compete in mental skills either. Prof. Byrne and colleague Lucy Bates found that elephants keep mental maps of at least 17 individuals in a travelling herd. The animals have poor eyesight and don't listen for calls, but instead use their sense of smell – when an elephant came across the urine scent from an individual they knew was behind them, which researchers put in front, they became confused. "I like the fact that it was a short-term memory ability, when everybody keeps saying elephants have a wonderful permanent memory," says Prof. Byrne.

So, what drives the evolution of intelligence? The leading theory is that complex cognition is an adaptation for dealing with the social interactions associated with living in groups.

> Belief that humans are special is being eroded. Naturalists are discovering more species that are also toolmakers

Social pressures

Group living creates competition between members of a society, so individuals must manipulate others – using tactics like deception and cooperation – to survive. This is the 'Machiavellian intelligence' or 'social brain' hypothesis, which suggests that larger brains evolved to understand social interactions. Indeed, group size is correlated with the size of the neocortex in mammals.

But group size can't explain all intelligent behaviour. Monkeys tend to live in larger populations than apes do, for example. And while primates can form stable polygamous societies, birds often live in monogamous couples in seasonal flocks, suggesting that a bird may need 'relationship intelligence' to understand their partner and maintain a pair bond. If so, the 'social brain' is another example of convergent evolution – both birds and primates have developed a large cortex to enhance social cohesion.

Evolutionary forces will depend on the species but, in general, intelligence is ultimately driven by ecological pressures. So if being smart helps them survive and reproduce, complex cognition should be favoured by natural selection, whether that is in birds, mammals or any other animal group.

"Almost everything for the last century has been based on primates," says Dr. Emery. "But I think there's a new focus, looking at lots of different species and thinking about why they've evolved their cognitive abilities – how it aids them in their struggle for survival, and how it relates to their brains." ■

INSIDE THE MINDS OF DOGS

What is your dog really thinking? **CAROLINE GREEN** and **ZOE CORMIER** reveal how our understanding of our four-legged friends is being revolutionised by new scanning techniques

When Dr. Attila Andics first suggested putting fully conscious dogs into MRI scanners to analyse their brains, his colleagues said it was "a crazy idea". But Dr. Andics, of the MTA-ELTE Comparative Ethology Research Group at the Hungarian Academy of Sciences, Budapest, not only persuaded 11 dogs to go along with his 'crazy' plan, but he also gained fascinating new insights into how dogs process language and emotion and a clue as to when we first evolved a voice.

But it's not surprising that Dr. Andics's plan was initially met with scepticism. Anyone who has ever undergone an MRI scan knows what an unsettling experience it can be. The scanner makes loud clanging, banging and screeching noises. Using scanners clinically in veterinary medicine is not in itself new but, in most cases, animals are put under general anaesthetic before entering the scanner. But for this study the dogs were all carefully trained to be able to lie motionless.

This breakthrough in being able to scan the brains of calm, alert and healthy animals "opens up the space for a completely new branch of comparative neuroscience," says Dr. Andics. "We could measure other things like smell and vision with directly comparative studies."

In particular, the Hungarian researchers are interested in the evolution of language in humans and what dogs can tell us about how

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A dog is prepared for an MRI scan as part of a research project at the Hungarian Academy of Sciences

our brains differ. Wolves became our first domesticated species between 14,000 to 31,000 years ago. "The normal social environment for a dog is a human family. That makes the comparison relevant," says Dr. Andics. "We hope to find aspects of language and speech processing that exist in humans but not in dogs. This will help us understand what made the evolution of human language possible."

Sit still

Dr. Andics's team played dog and human sounds through headphones to 11 dogs that had been trained to lie completely still in the scanner, then did the same with human volunteers.

"We compared the average activity for dog and human sounds, and identified the brain regions where activity levels for the two sound types were significantly different," he says.

This allowed them to identify that the temporal pole region of the brain was one of the active areas involved in both cases, and that each species showed a heightened response to its own kind.

"We also found that both dog and human brains process emotional information in dog and human sounds very similarly," says Dr. Andics.

The animal responds to human emotions in the same way that it responds to dog emotions, albeit on a lesser scale. In effect, when your pup looks at you with those big, sad eyes when you're having a bad day, you might not be guilty of mere anthropomorphism – the projection of human characteristics onto animals. Fido might really be feeling your pain.

However, while dogs dedicate a healthy percentage of their auditory cortex to human voices, they are far more attuned to the environment than we are. In dogs, 39 per cent are responsive specifically to dog vocalisations, 13 per cent to human voices, but the largest slice goes to environmental noises at 48 per cent. By contrast, just three per cent of the human auditory cortex is specialised to respond to environmental noises, and a whopping 87 per cent of our brain is specialised for the voices of

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A scan of a bulldog's brain from a veterinary clinic. Unlike Dr. Andics's dogs, it was put under general anaesthetic.

GETTY IMAGES

other humans. Of course, vocal communication is an extremely important characteristic of our species.

So the big question is – did voice-sensitive regions evolve independently in humans and dogs, perhaps due to our shared environment? Or is the root of this region far older – and do other mammals have a voice-specific region of the brain too?

Indeed, monkeys have been tested in MRI scanners, and a 2008 study by the Max Planck Institute in Germany found that they too have voice-specific regions in the auditory cortex of their brains. The study indicates that the last common ancestor of humans and monkeys

> Both dog and human brains process emotional information in dog and human sounds very similarly
>
> *Dr. Andics, Hungarian Academy of Sciences, Budapest*

would have had a voice-specific region, dating to at least 30 million years ago. This is when monkeys and apes went their separate ways on the evolutionary tree – humans are descended from apes.

But it could be much older. "Our study of dogs would put the origins of the voice specific region at 100 million years ago," says Dr. Andics. This is when the evolutionary path of a common ancestor diverged. "This means the same region could exist in cats, whales, rodents and bats."

This is only the first comparative neuro-imaging experiment of a non-primate species and humans, and so more studies should provide answers. With Dr. Andics planning further work into how dogs process language, it may not be long before we know more of our pets' minds. ■

MENTAL

THE LATEST RESEARCH ON BRAIN CONDITIONS


HEALTH


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THE SCIENCE OF SANITY

Over the last century, almost 250 new psychiatric conditions have been identified, from attention deficit disorder to hoarding disorder. **JO CARLOWE** investigates the fine line between what is considered sane and insane

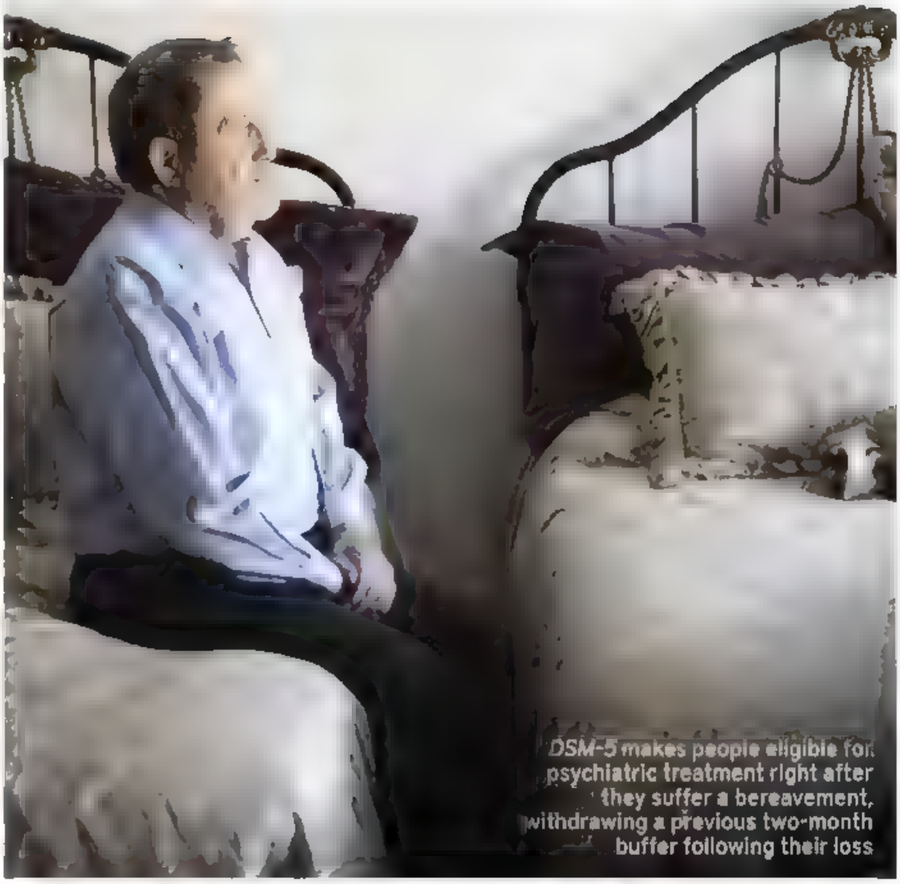
They say there's a fine line between sanity and madness. Back in 2013 that line became more blurred, thanks to the publication of a book. The Diagnostic And Statistical Manual Of Mental Disorders (DSM) is the American Psychiatric Association's 'bible'.

But in the months following the publication of the fifth edition, it generated a storm of controversy. Critics argued that it classified what should be considered ordinary behaviour as madness, with the British Psychological Society warning that normal experiences would be given "potentially stigmatising medical labels" and result in "potentially harmful interventions".

First published in 1952, the DSM is a practical guide for psychiatrists, with a check-box of symptoms for all recognised mental health conditions. The idea is that psychiatrists match their patients' complaints against them to find an appropriate label: bipolar, acute stress disorder, somatic symptom disorder (hypochondria) and so on.

The new edition was the first time the American Psychiatric Association (APA) had fully updated the DSM in nearly two decades. The furore was caused by the 15 new mental →

disorders included in the new edition. Becoming overwhelmed with grief when a loved one dies was now diagnosed as 'major depressive disorder'. Getting horribly nervous before a speech might mean you have 'performance only social anxiety disorder'. Even failing to throw out old junk could have you labelled with a 'hoarding disorder'.



DSM-5 makes people eligible for psychiatric treatment right after they suffer a bereavement, withdrawing a previous two-month buffer following their loss

Good grief

It was the removal of 'the bereavement exclusion' that caused the most concern. This advised doctors to refrain from diagnosing major depression in individuals within the first two months following the death of a loved one.

By doing away with this, critics said DSM-5 made insanity of grief. Defending the decision was Dr. David Kupfer, who presided over the DSM-5 Taskforce. He said that the exclusion was unhelpful, because it suggested "grief somehow protects a person from major depression", leaving some unable to access help.

Critics included Dr. Allen Frances, a former DSM Taskforce chair, who believed that the updated manual reduces the ranks of the normal. "Grief becomes 'major depressive disorder', worrying about being sick is 'somatic symptom disorder', temper tantrums are 'disruptive mood dysregulation disorder', gluttony is 'binge eating disorder', and soon almost everyone will have 'attention deficit disorder'," he said.

The fifth edition of the DSM lists nearly 300 psychiatric disorders

Dr. Frances is not alone in expressing dismay at DSM's ever-growing reach. "The number of diagnoses has been quietly increasing," notes Professor Simon Wessely of the Institute of Psychiatry, King's College London.

In 1917 the American Psychiatric Association (APA) recognised just 59 psychiatric disorders. Today the manual lists nearly 300.

The APA itself, however, provides different figures – it says that DSM-5 officially includes just 157 disorders. But it depends what you include. Some disorders are excluded as they come under the heading 'for further study', while others are subdivisions of disorders that used to stand alone. Common consensus is that there are 297 disorders in DSM-5, but what's indisputable is the fact that DSM has grown fatter. In 1952 it had fewer than 150 pages, while today it's just under 1,000.

The origin of the DSM

The DSM has its origins in a military manual, Medical 203, created after World War II to classify the mental health problems of returning soldiers. Previously, there was no 'dictionary' of definitions. What one doctor might call 'depression', another might label – and treat – differently.

DSM was a way around this. It was intended as a research tool, but what was essentially a detailed textbook soon became a user manual. It really took off in 1980 when the third edition ushered in a new diagnostic era for psychiatry. It included 80 new disorders and made us familiar with conditions, such as 'social phobia' and

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Isle of Wight resident William Brett hasn't thrown anything away, so his house includes decades' worth of artifacts. 'Hoarding disorder' is in DSM-5

ALAMY

'major depression'. Critics, though, claim the rise in disorders wasn't based on tangible new evidence – for example, social phobia was simply shyness repackaged.

In his book *Cracked: Why Psychiatry Is Doing More Harm Than Good*, psychological therapist Dr. James Davies described how the content of DSM-III was determined not by hard science but by committee. A taskforce of psychiatrists decided what to include, with the most vociferous getting their way. Dr. Davies wrote that a potential symptom was even junked when a taskforce member pronounced: "We can't include that...because I do that!"

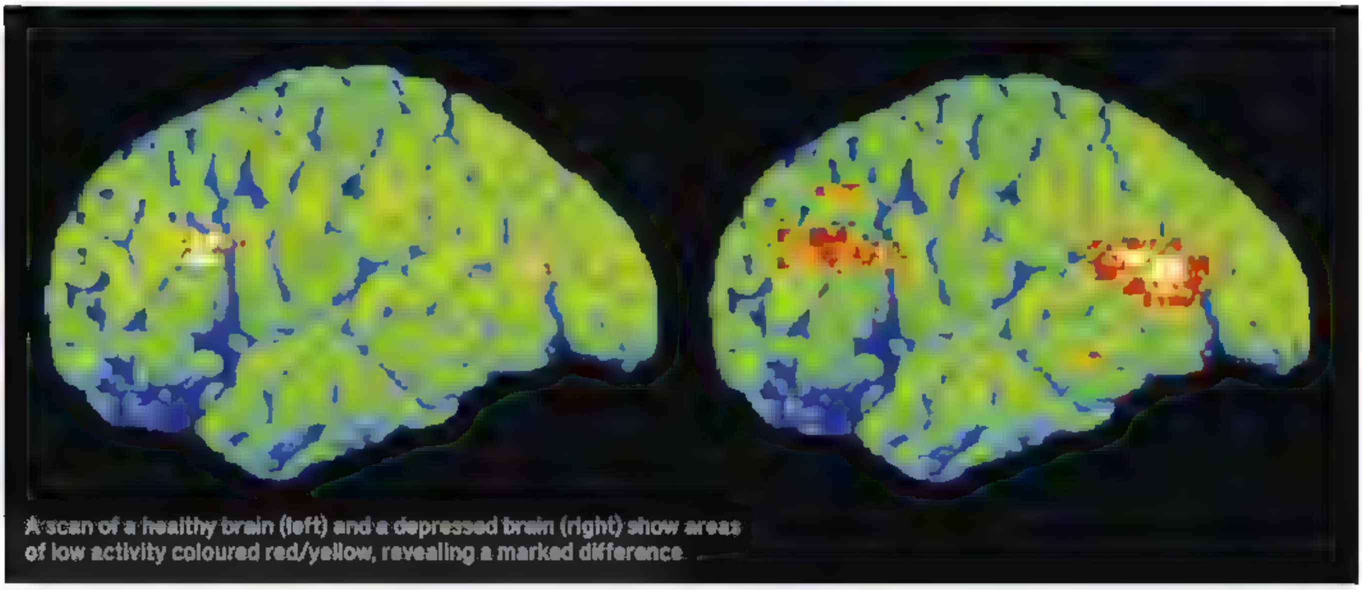
Higher standards have been applied to later editions. DSM-5 was compiled by over 160 world-renowned clinicians who evaluated reams of evidence. And yet, there are still no laboratory tests to conclusively diagnose most mental health conditions, including depression and bipolar disorder. Only a handful of mental disorders, such as Alzheimer's, have an identifiable pathological basis. Opponents say this makes DSM-5 no more scientifically valid than its predecessors.

"Scientists have failed to find biological markers for nearly all mental disorders, because the disorders for which markers are being sought actually have no sustained reality in anything other than the manuals themselves. This is not to say people don't suffer. It's to say that suffering is less uniform and less easily categorised than these manuals have led us to believe," says Dr. Davies.

There are still no laboratory tests to conclusively diagnose most mental health conditions, including depression

Nick Craddock, Professor of Psychiatry at Cardiff University, admits the approach is limited. "In psychiatry we rely on the description a person gives and then we have to use that description to arrive at the most appropriate diagnosis. That is the best we can do at the moment."

But, while Prof. Craddock is critical of DSM, he supports the need for a system of classification. "People have attacked DSM's shortcomings as a way of saying the whole notion of psychiatric diagnosis is ridiculous. I'm convinced of the need for a system of diagnosis. It's crucial for helping guide patients towards the best treatments based on knowledge that has been accumulated from research. My own view about DSM-5 →



A scan of a healthy brain (left) and a depressed brain (right) show areas of low activity coloured red/yellow, revealing a marked difference.

is that it was the wrong time to be trying to develop a new version. It is not better, but it is probably not massively worse."

Prof. Wessely goes further, dubbing DSM-5 a "public relations disaster" for psychiatry. But chances are that professionals who are critical of DSM, will also be critical of other classification systems. For example, the World Health Organization also produce a manual, called the International Classification Of Diseases (ICD).

"The real pressure is not trying to see more patients and making more diagnoses, it's the opposite," says Prof. Wessely. "Most psychiatrists are defending their services to protect their ability to treat those who have very serious recognised disorders, irrespective of the classification system."

If not ICD or DSM – what then? Dr. Davies hopes both manuals become obsolete, advocating instead a World Health Organization publication called the mhGAP Intervention Guide. It includes just 11 categories of disorders. But Dr. Kupfer says that DSM does have a future. He anticipates "incremental updates" that are responsive to the latest research. The push for new science is backed by the Royal College of Psychiatrists in the UK and the National Institute of Mental Health in the US – both have called for "new research directions" to improve mental illness diagnosis.

Seeing the light

In many ways, psychiatry remains in the Dark Ages. But advances in neuroscience could well put an end to the DSM debate. Prof. Craddock likens the situation to cardiology before the workings of the heart were fully understood and before the invention of the electrocardiogram.

"At the moment we are in that 100 years ago phase in psychiatry, where we are just relying on people's descriptions of how they are feeling as a proxy for what is going on in their brain," says Prof. Craddock.

Advances in molecular biology, genetics, and brain imaging will change this. "With brain imaging we can directly observe what is happening in someone when they are struggling to think of something, hearing voices, having a severe depression or mania," he explains.

Scientists are already using functional magnetic resonance imaging (fMRI) to watch brain activity while people problem solve or view pictures that trigger emotional responses. In the fall of 2013, imaging by US researchers revealed brain tissue loss in patients with schizophrenia; another study discovered 13 new locations in our genetic code linked to the development of schizophrenia.

Prof. Craddock believes that in just 20 years' time, psychiatrists will be able to supplement standard questions about a patient's symptoms and medical history with tests that can objectively diagnose conditions, such as bipolar disorder. "We're about one generation, just 15 to 20 years, away from this. People will look back and think that the particular diagnostic categories in DSM were all a bit quaint." ■

"With brain imaging we can directly observe what's happening in someone with depression"

Prof. Peter Dayan, University College London

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Addiction or habit

[illegible]

CLUTTER COLLECTORS

Cherishing your prized collection of LPs may seem like harmless nostalgia but, when taken too far, DSM-5 views it as insanity. While old editions of DSM listed hoarding as a symptom of obsessive compulsive disorder (OCD), DSM-5 gives it a category of its own. The main [illegible] persistent difficulty discarding or parting with possessions, and DSM estimates that up to five per cent of Americans are afflicted. This means that in the US alone, an additional 16 million previously 'normal' people are now potentially insane.

GAMING ENTHUSIASTS

The recurrent use of online multi-player games, and a preoccupation with them, can result in clinically significant impairment or distress, says DSM-5. Although 'Internet gaming disorder' is not included in the manual as a formal disorder, it is mentioned under the heading "Conditions for further study". So while frequent all-nighters playing Minecraft may be okay for now, gamers beware. Your days among the ranks of the 'normal' may soon be numbered. The criteria are currently limited to gaming and not social networking.

COFFEE DRINKERS

Cranky and tired from a lack of coffee? DSM-5 considers it to be more than just a caffeine headache. While the previous edition included 'caffeine intoxication' among the more controversial conditions, the new one has gone a step further, listing 'caffeine withdrawal' under 'caffeine-related disorders'. This is squashed neatly between the sections on alcohol and cannabis. To qualify as 'psychiatrically unwell', your caffeine withdrawal will need to cause 'meaningful mental anguish' or disrupt some key aspect of everyday life.

ALAMY / GETTY IMAGES

5 THINGS THAT GET YOU HOOKED

Are you constantly craving chocolate? Have you tried to quit smoking – but never succeeded? Do you struggle to put down your phone? Discover the science behind addictions.

1 Food

Global obesity has more than doubled since 1980. In 2014, more than 1.9 billion adults were overweight. And by 2025, one-fifth of adults worldwide will be obese. Sugar-heavy food is partly to blame. And one study, at Connecticut College in 2013, suggested that Oreos were "as addictive as cocaine" – at least for rats. But can we be addicted to food?

To decide, first we need to understand what addiction is. The criteria for diagnosing substance addiction disorders in the psychiatrist's bible, the *Diagnostic and Statistical Manual of Mental Disorders* (DSM), include developing a tolerance, having withdrawal symptoms and becoming dependent.

The involvement of the brain is key to diagnosing addiction. Addiction affects areas of the brain that are linked to pleasure, reward and decision-making. It also affects the chemical signals which are used for communication between brain cells and brain regions, known as neurotransmitters.

Over time, memory of previous exposure to rewards (such as food, sex, alcohol or drugs) leads to a biological response, such as cravings. The best tool so far that researchers have for applying all this to food is the Yale Food Addiction Scale (YFAS). Ashley Gearhardt, an assistant professor of clinical psychology at the University of Michigan, who co-developed the YFAS in 2009, believes addictive processes do play a role in eating-related problems. "We're not using body weight to identify people who could be addictive eaters, instead we're using the same criteria we'd use for any addiction."

In one experiment, Gearhardt showed people pictures of 'treats' such as chocolate milkshakes, then gave them the real thing. She found that people who have more 'addictive-like' eating behaviour have more activity in brain regions linked to reward and desire when exposed to 'addictive cues' than when they saw other images. They also have less of an inhibitory response in their brains once they have drunk a chocolate milkshake than after consuming other non-addictive foods. But Dr Hisham Ziauddeen, a senior researcher in food reward processing at the University of Cambridge, feels the YFAS undermines the idea of food addiction as a medical condition. "People who score highly also score highly for some of the more conventional eating disorders."

Addictive cues

Some researchers go further, and say food addiction is a potentially dangerous public health message. Ian Macdonald, a professor of metabolic physiology at the

"…could be because it's difficult to reconcile an addiction with something that is essential to human life. Things like alcohol and drugs are, essentially, choices – eating is not. Everyone must eat to survive, so an addiction has to be something much more extreme than normal eating."

The big question is, does being told a food is

People who completed the Yale Food Addiction Scale identified pizza as the most 'addictive' food of all

addictive strengthen or weaken your New Year's resolution to eat healthily?

Professor Peter Rogers, who studies nutrition, behaviour and the brain's control of appetite at the University of Bristol, says labelling food addiction as a condition could have unpredictable ... s. His research, published in ... journal *Appetite*, looked at ... giving information about food addiction affects people's ... had either proven or ... ood addiction, b... e test of healthy and ...

... ople who had just read that food addiction w... there was an interes... Prof. Rogers explains. ... people ate a lot, some very little. Which fits the theory that ... people think 'I can't help m... and succumb, while others think 'these foods are addictive' and refrain. So one implication is that the more people read about food addiction, the more they have a particular mindset."

This may sug... a possible treatment for proble... is a... hat should be avoided. Before deciding on possible treatments, though, there ... to be a ... hether food addi... sts, and ... agreed on these points. Clearly ... rtain people do crave certain ... but we don't understand fully what drives these cravings, what reward people get from eating the foods they c... there's still plenty to chew over.

Dried opium poppy seed heads can be chemically processed to produce heroin

2 Drugs

The science of how illegal substances get you hooked

Heroin. Ecstasy. LSD. These Schedule 1 drugs give huge highs, but most are also hugely addictive. They work by interfering with neurotransmitters – the chemicals that transmit signals around the brain – and their receptors. This causes changes to the brain's reward system, which can create craving and tolerance, so that a higher dose is needed to have the same effect. Some drugs also have unpleasant withdrawal symptoms that are only relieved by taking more.

Heroin is the most addictive drug known. It mimics the brain's own endorphins, the natural opioids that induce pleasure and reduce pain. The brain responds by reducing the sensitivity and number of its opioid receptors, so that more of the drug is needed.

In an attempt to put a stop to the downward spiral, researchers are currently trying to find ways to target memories linked with drug use. A 2013 study, led by Dr. Courtney Miller of the Scripps Research Institute in San Diego, sought to help methamphetamine addicts by targeting the removal of memories linked with drug use.

Neurons connect to each other through small structures known as dendritic spines – which is where memories are thought to be physically stored. The spine structures are maintained by 'scaffolding' made up of individual units of actin, which combine to form long chains that can enlarge spines and store memories by stabilising specific connections between neurons.

"With your run-of-the-mill memory, the individual units of actin cycle very slowly – one comes off the top, another is added to the bottom," says Dr. Miller. "But with memories formed when taking methamphetamine, these units move very fast, and the actin chains fall apart. So we think we're able to selectively target drug-associated memories, and hopefully traumatic memories in the future, because the brain is using a different mechanism to store these memories."

→

3 Sex

While it's an easy excuse for celebrity infidelity, scientists cannot agree as to whether sex addiction actually exists

'Hypersexuality' or 'compulsive sexual behaviour' is not currently listed in the psychiatrist's manual, the DSM. Indeed, research into sex addiction only began fairly recently.

One of the first studies, that was carried out by the Department of Psychiatry at the University of California in 2013, used EEG (electroencephalography) to analyse the brain's response to sexual stimuli in people that struggle to control their use of online pornography.

"Hypersexuality does not appear to explain brain differences in sexual response any more than just having a high libido," Dr Nicole Prause told *Psychology Today*.

Intriguingly, the results also showed that the brain does not respond to sexual imagery in the same way that a drug addict's brain does to pictures of drugs.

But a more recent study by Dr. Valerie Voon from the University of Cambridge, found exactly the opposite. Functional magnetic resonance imagery (fMRI) showed that pornographic videos increased activity in brain regions linked with emotion and reward, which are also switched on in drug addiction.

So, it seems that the verdict is still out as to whether sex addiction really exists. As Dr. Marc Potenza from the Yale School of Medicine, says: "More evidence must be gathered about this question."

Researchers using an MRI machine to record the brain's response to sexual foreplay

4 Nicotine

How this addictive substance affects the brain – and why smokers struggle to quit

Cigarette smoking is still one of the leading causes of premature death in the US. On average, 435,000 people die early from smoking-related diseases each year, and 50 per cent of lifelong smokers will die prematurely. So why do smokers keep lighting up? For many, the answer is addiction.

When smoke particles are inhaled into the lungs, nicotine is rapidly absorbed into the bloodstream. After inhalation, nicotine can reach the brain within 10 seconds, where it binds to ion channels, opening them to allow the passage of sodium and calcium. As the calcium enters a neuron, it releases neurotransmitters, such as the pleasure-inducing dopamine.

Despite knowing tobacco is bad for health, of the 35 million people that seriously try to quit each year, less than seven per cent stop smoking for good.

5 Internet

Some experts think gadgets, gaming and the net bring out people's addictive tendencies

Back in 1995, New York psychiatrist Ivan Goldberg declared in an online post that he had discovered a new addiction. People were abandoning traditional face-to-face social situations in favour of sitting glassy-eyed in front of a computer screen, endlessly surfing the net and playing online games. He dubbed the condition 'Internet Addiction Disorder'.

But Goldberg's post was actually a spoof intended to satirise our obsession with addictive behaviours, and classify any abnormality as an addiction.

Despite this inauspicious start, many behavioural scientists felt that Goldberg had hit on something. Internet Addiction Disorder is not listed in the latest edition of the psychiatrist's DSM manual, but it is seen as a condition requiring further study.

Professor Mark Griffiths, a psychologist at Nottingham Trent University in the UK, and Director of the International Gaming Research Unit, has been researching internet addiction since 1995. He believes it does exist, but wants to be careful about how cases are classified.

"People genuinely addicted to the internet are actually few and far between," says Prof. Griffiths. "That's not to say people don't use it excessively, but excess is totally different from addiction. And someone can be an internet gambling addict, an internet shopping addict, or an internet sex addict, but these people are not addicted to the internet. They are addicted to gambling, shopping, or sex. The internet is just a medium to fuel those predisposed behaviours."

With gaming and internet usage on the rise, particularly with the younger generation, the big question is how to treat those who are genuinely addicted. At the Tavistock Clinic in London, Dr. Richard Graham deals with adolescents obsessed with gaming or using the internet. "We certainly see patterns of behaviour that fit with descriptions of addiction, but I think there are complexities to this that do need teasing out."

As far as treatment goes, Dr. Graham carries out an assessment of his patient's particular needs, then designs a programme of small steps aimed at returning to a normal life. "In some cases I have used medication," he says, having prescribed both anti-depressants and drugs for anxiety to patients whose gaming becomes depressive. "People get very low, particularly if things go wrong in their game. Sometimes we must be quite firm and literally switch off the modem." ■

"Someone can be an internet gambling addict. But they are not addicted to the internet, they are addicted to gambling"

Prof. Mark Griffiths, Nottingham Trent University

GETTY IMAGES / WORDS BY LILIAN ANEKWE, MARK BLACKMORE, SUSAN BLACKMORE, JHENI OSMAN

ALZHEIMER'S THE SEARCH FOR A CURE

With one in nine over 65 year olds in America suffering from this debilitating disease, the race is on to find a treatment. **ROBERT MATTHEWS** looks at the latest research

Todd* suddenly lost his way along a familiar path. Like his companion, also in his late 60s, he laughed it off as just a momentary lapse – a 'senior moment'. But it would be their last trek together.

Over the months that followed, Todd became increasingly forgetful and tetchy. Persuaded to see a doctor, he underwent tests and got a diagnosis – he had joined the one in nine Americans over 65 with Alzheimer's disease (AD).

Todd's condition followed the classic trajectory of this most common form of dementia. The regions of his brain involved in short-term memory, planning and thinking were the first to be affected. Then the disease started to spread elsewhere, killing cells in such numbers that his whole brain began to shrink. Personality changes set in, along with problems talking to or even recognising family and friends.

After a few years, Todd became so weak that he became permanently bed-ridden. Finally, five years after diagnosis, his health suddenly deteriorated and he succumbed to pneumonia – the common fate of most AD patients.

Globally, almost 50 million people are following a similar path as this degenerative brain disease takes hold. And in a cruel twist to the global good news story of increased life expectancy, that figure is set to explode to over 130 million by 2050, as more people survive into old age.

Yet even those grim statistics are eclipsed by the most stark fact about AD. Despite all the breakthrough claims, medical science still has little to offer those diagnosed with this devastating disease. This seems to fly in the face of the standard story about AD: the cause is known and a cure within reach.

According to this narrative, AD is the result of a build-up of a sticky protein in the brain, known as amyloid-beta, which creates so-called plaques and tangles in brain cells that then malfunction and die. It thus seems clear that in the quest for a cure, the target should be combating amyloid and its effects. For decades that's exactly what researchers and pharmaceutical companies have been doing. But it isn't working.

Veteran AD expert Dr. Jack de la Torre of the University of Texas, Austin, puts it bluntly: "The field of Alzheimer research has reached an impasse after more than 100,000 clinical and scientific papers published in the last 40 years," he says. "There is yet no hope, no effective treatment, and no knowledge of what causes dementia."

Breakthrough drugs

At first, the prospects seemed bright. In 1993, the US Food and Drug Administration (FDA) approved Tacrine, the first drug to be widely marketed for combating the symptoms of AD.

The drug was supposed to compensate for the impact of AD on cognitive ability by boosting levels of a neurotransmitter acetylcholine. But the improvements it produced were modest – and came at the price of serious side-effects. In 2013, these led to Tacrine being withdrawn from the market.

Over the years, around 400 therapies for AD have reached the stage of being tested in human trials, but virtually every one has failed. Even headline-grabbing 'breakthrough' drugs, such as Aricept, have proved only marginally beneficial with most patients.

Hopes that genes would unlock the mystery of AD and lead to a cure have also proved misplaced. During the early 1990s, researchers seemed on the brink of a huge advance with the discovery of a gene code-named APOE-epsilon4.

Studies revealed that around one in five people carry a single copy of this gene on their DNA, and as a result face a four-fold higher risk of AD, soaring to 10-fold for the one in 50 carrying two copies. The obvious question was: why?

In 2008, scientists at Case Western Reserve University, Ohio, discovered that the gene seems to affect the ability of brain cells to clear away the sticky amyloid protein fragments that form plaques.

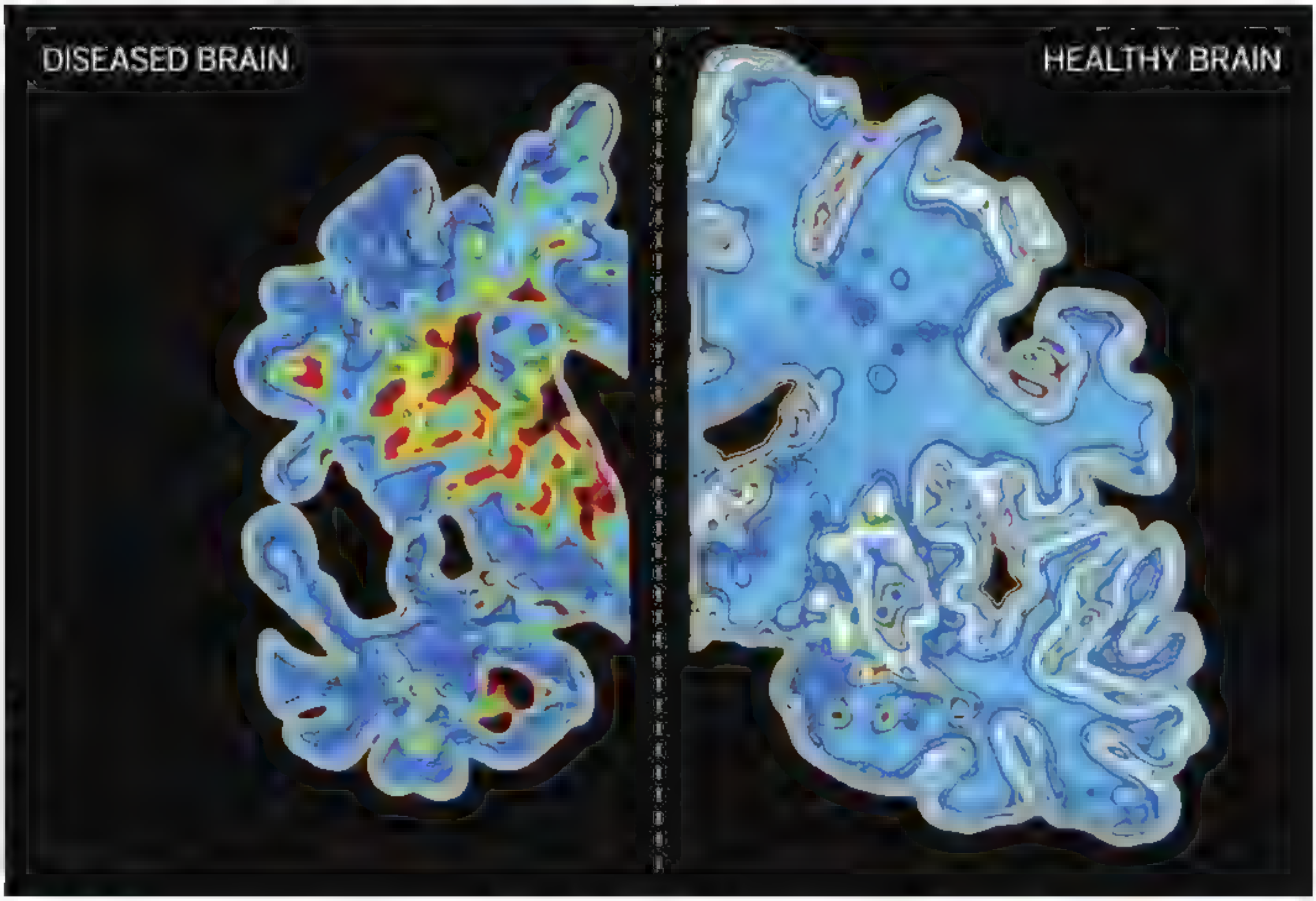
Then, in 2012, the same team made headlines worldwide by showing that an old anti-cancer drug called bexarotene dramatically boosted this 'house-cleaning' ability of brain cells. In experiments, the drug seemed to clear away plaques, leading to improved brain function. There was, however, a caveat: those benefiting were mice, not humans.

Using animals as substitutes is problematic with any drug, but →

In a cruel twist, the number of dementia sufferers is set to explode to over 130 million by 2050, as more people survive into old age

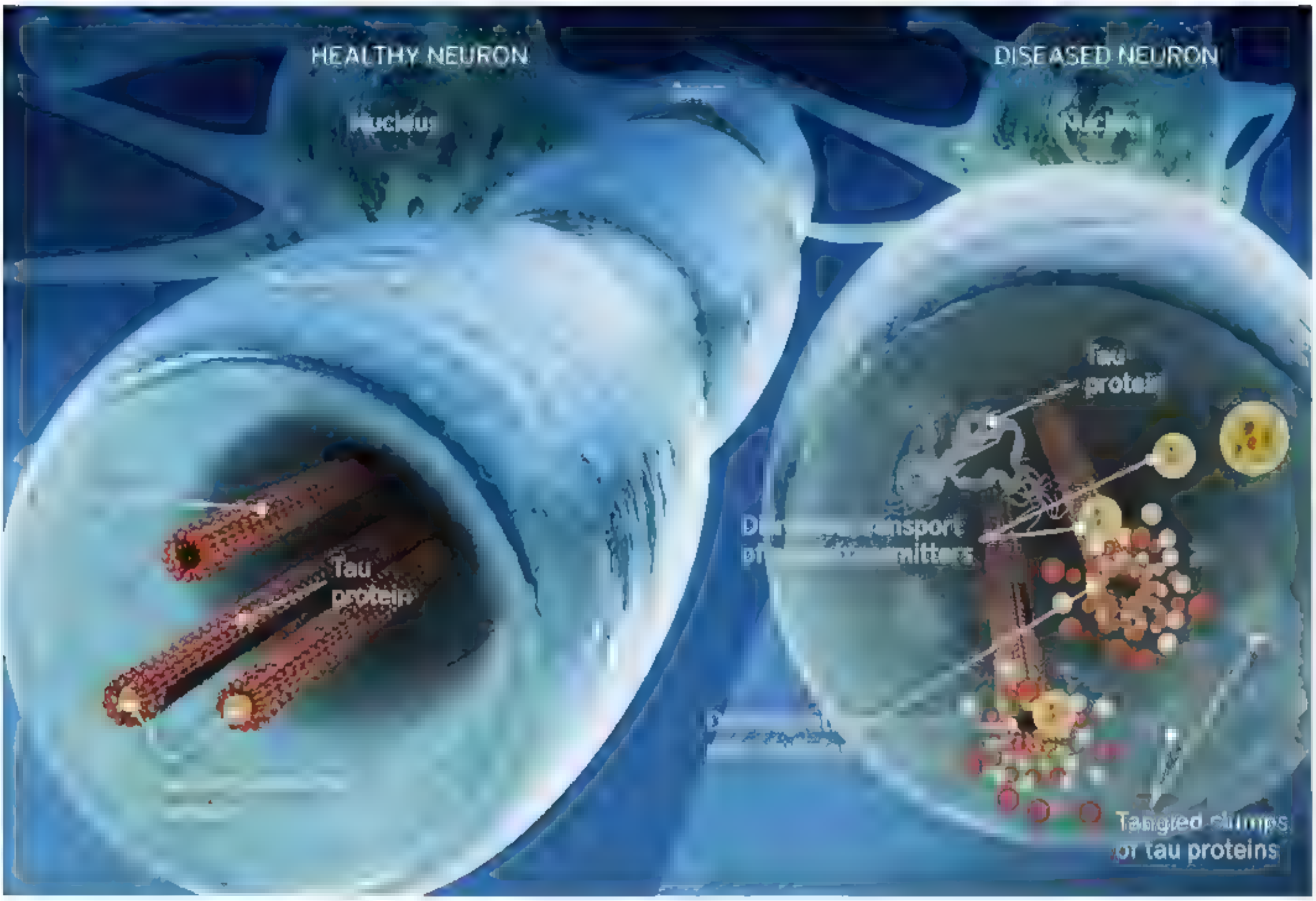
*Name has been changed

AGEING POPULATION One in nine Americans over the age of 65 suffer from Alzheimer's disease. Almost 50 million people live with the condition worldwide, and this figure is expected to rise to over 130 million by 2050



ALAMY / SCIENCE PHOTO LIBRARY

CELL DEATH A computer graphic of a vertical slice through the brain of an Alzheimer's patient (left) compared with a normal healthy brain (right). The brain of the Alzheimer's patient is considerably shrunken, due to the death of neurons



BREAK DOWN In a healthy neuron (left), tau proteins bind microtubules together, ensuring neurotransmitters pass through the vesicle. In a diseased neuron (right), the tau proteins break down and microtubules disintegrate, disrupting the transport of neurotransmitters

BRAIN BOOST Omega-3 fatty acids, found in foods such as fish, are thought to be good for the brain. But new research suggests that Omega-3 supplements may not protect from dementia after all

FIGHTING FIT Exercise can have a significant impact on the wellbeing of people living with dementia, as it improves strength and sleep, and helps to maintain a healthy heart and blood vessels

SCIENCE PHOTO LIBRARY / GETTY IMAGES

has proved especially so with AD – and attempts to confirm the finding failed. Earlier this year, the outcome of the first human study also proved negative.

The story is not quite over yet. Lead investigator Dr. Jeff Cummings, of the Lou Ruvo Center for Brain Health in Las Vegas, points out that this was only a small pilot study. "The observation definitely needs to be replicated and followed up," he says. "The next step in the development programme will be a larger trial."

Bexarotene may thus join several other anti-plaque compounds currently in full-scale clinical trials. They include widely-publicised 'monoclonals', such as solanezumab, specially designed to seek and destroy amyloid protein like guided missiles.

Yet despite being hailed as a "massive step forward" even by the Government Health Secretary, these too are widely expected to fall well short of the hype when results begin to emerge later this year.

A change of direction

This seemingly endless stream of disappointment has prompted concern that perhaps the decades-long focus on plaques is simply misguided. It's a view backed by an intriguing fact: while most AD patients have high levels of plaque, similarly high levels have also been found in around one-third of people with no sign of dementia at all.

The idea that there's something else involved won a boost earlier this year from new brain scanning studies by a team from Washington University School of Medicine, St. Louis. These have focused on another brain protein called tau, which plays a role in keeping neurons healthy and tangle-free.

Defects in tau have long been linked with AD, and the team found that levels of this protein may be better predictors of cognitive decline than amyloid protein alone. "What we suspect is that amyloid changes first and then tau," says lead researcher Dr. Beau Ances. "It's the combination of both that tips the patient from being asymptomatic to showing mild cognitive impairment."

But some researchers insist the lack of progress in finding a cure demands a more radical re-think. Earlier this year, the highly respected *Journal of Alzheimer's Disease* published an editorial with over 30 co-signatories calling for research into the possibility that infections cause AD.

The lead author was Dr. Ruth Itzhaki of the University of Manchester, who has long suspected that both amyloid and tau protein levels are just symptoms of the true cause of AD.

For over 25 years, she and her colleagues have been gathering evidence that agents like the herpes simplex virus lie dormant in the brain for decades, but then burst back into action and attack cells as our disease-fighting abilities decline.

If true, this raises the astounding possibility that at least some cases of AD could be treated using standard drugs like antivirals.

While many researchers are sceptical of the 'dormant infection' theory, some have given it a cautious welcome. "These observations are interesting and warrant further research," says Dr. James Pickett, head of research at the Alzheimer's Society. But he adds: "There is currently insufficient evidence to tell us that microbes are responsible for causing Alzheimer's disease in the vast majority of cases."

Reducing the risk

While scientists argue the merits of the different theories, evidence is growing that we can all reduce the risk of developing AD. Studies suggest that keeping mentally and physically active in later life, and switching to a 'Mediterranean' diet rich in fruit, vegetables, olive oil and fish can be beneficial. Again, the strength of the evidence has often been hyped, but most of the measures are already known to boost general health and so are worth trying regardless of their impact on AD risk.

While scientists argue over the direction the quest for a cure should take, everyone agrees about the need to address chronic underfunding of research. Astonishingly, for every dollar spent by the US on care of those affected by AD, less than a penny is spent on research.

"We have made great strides in treating and preventing many diseases – even major killers such as cancer, heart disease, and HIV/AIDS – when we have made the issue a high priority and the resources available for research," says Dr. Maria Carrillo, Chief Science Officer of the US Alzheimer's Association. "Now is the time to do the same for Alzheimer's disease." ■

If true, this raises the astounding possibility that at least some cases of AD could be treated using standard drugs like antivirals

THE POWER OF MUSIC

Listening to music can have profound effects, from making you more intelligent to curing insomnia. **JOHN POWELL** delves into the psychology of music.

HOW DOES MUSIC AFFECT THE BRAIN?

Music can help to control the release of certain chemicals in your brain and blood supply. Stressed people often have too much adrenaline and cortisol in their system, so they are perpetually in a fight or flight mode. Music inhibits the release of these chemicals and encourages the release of pleasure-related chemicals such as dopamine and serotonin.

WHY IS OUR MUSICAL MEMORY SO GOOD?

Most of us can remember the finer details of musical pieces we haven't heard for years. People who have suffered serious memory loss due to accidents or disease often retain their musical recollections, and these can even be effective in restoring speech in stroke patients who have lost the ability to speak. We know that music is processed in lots of different areas of the brain, so could this be why musical memories are able to survive local brain damage?

CAN MUSIC HELP YOU SLEEP?

Music has been shown to cure insomnia. In a study involving young adult insomniacs in Budapest in 2007, over 80 per cent of the participants became good sleepers after three weeks of listening to classical music at bedtime. In a similar investigation involving Taiwanese insomniacs aged over 60, half of the participants were transformed into good sleepers within a few weeks.

If you have trouble drifting off to sleep, make a 45-minute-long playlist of calming music (an adult takes 10 to 35 minutes to drop off), and make sure the final track fades out gradually – otherwise the abrupt silence at the end will wake you up (one of our survival instincts is to wake up if things go suddenly quiet).

GETTY IMAGES

CAN MUSIC AFFECT BEHAVIOUR?

[illegible]
professor Ronald Milliman discovered that slow,
[illegible]
drinks. Indeed, research shows that the correct choice of background music can increase the
[illegible]
items you buy. In one test, carried out by
[illegible]
1999, German wine sold twice as fast if
[illegible]
when French accordion music was being piped out, the French wine was *five times* more popular
[illegible]
method'. In 2006, Sydney's city council was trying
[illegible]
off to find somewhere cooler to hang out

HOW DOES MUSIC MANIPULATE OUR EMOTIONS?

Perhaps the most obvious example of this is when we're watching a film. If the director wants to make you jump, a sudden loud noise (or musical sound) is very effective in triggering your fight-or-flight response, which will flood your system with adrenaline and cortisol. Your brain subconsciously assumes that you're in danger because we have evolved to associate any unexpected noise (even music) with a possible threat. This is why the eee! eee! eee! shower scene music in the film *Psycho* is so terrifying.

ISTOCKPHOTO / GETTY IMAGES

DOES LISTENING TO CLASSICAL MUSIC MAKE YOU MORE INTELLIGENT?

Back in 1993, US psychologist Frances Rauscher and her colleagues published a paper which gave birth to the so-called 'Mozart effect'. In this study, students were given a spatial reasoning IQ test, before which they had either sat in silence for 10 minutes, listened to relaxation instructions, or listened to a Mozart piano piece. The researchers found that those who had listened to the piano piece had noticeably higher scores than the other two groups.

But by 2010, psychologists had worked out that it had nothing to do with Mozart. E. Glenn Schellenberg and his team at the University of Toronto, proved that your score in an IQ test can be improved simply by listening to any stimulating music you enjoy (Schubert and Blur worked as well as Mozart). A similar result could even be achieved by listening to a Stephen King short story.

The effect works by raising the level of a neurotransmitter in your brain called norepinephrine, which increases your level of alertness and helps you to cope with the test.

On top of this, the enjoyable music increases your dopamine level, helping put you in a buoyant and confident mood. ■

ISTOCKPHOTO

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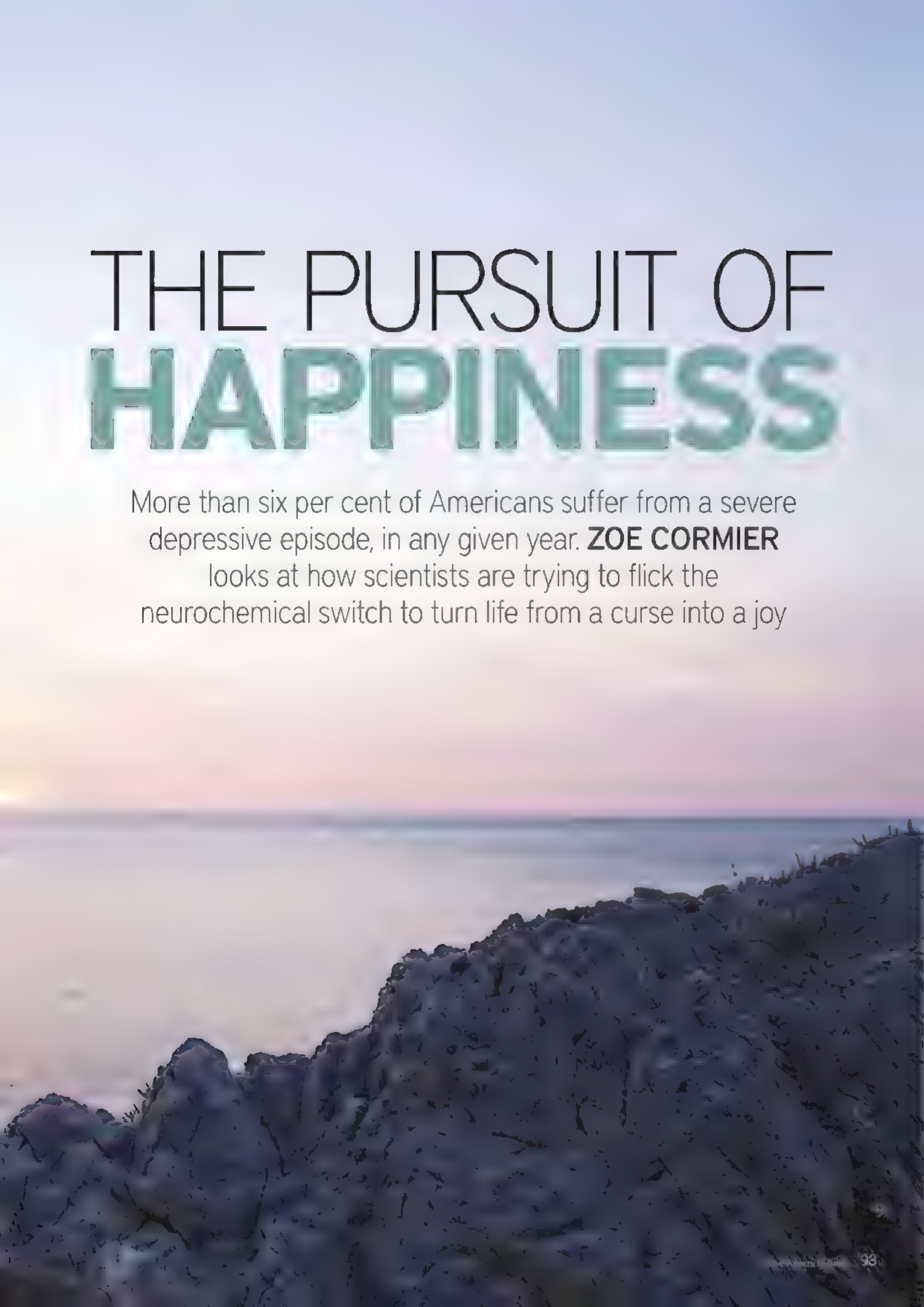
THE PURSUIT OF HAPPINESS

More than six per cent of Americans suffer from a severe depressive episode, in any given year. **ZOE CORMIER** looks at how scientists are trying to flick the neurochemical switch to turn life from a curse into a joy



Neurotransmitters, such as serotonin, pass across synapses, which are the junctions between two nerve cells (neurons)

Depression affects an estimated 350 million people around the globe. And this common mental disorder is the leading cause of disability in the developed world, according to the World Health Organization. So what goes on inside our brains to create such malaise?

The idea that depression is linked with an imbalance in the levels of the neurotransmitter serotonin is outdated. And the mainstream media has over-simplified how anti-depressants work – claiming they simply 'top up' serotonin levels.

While it is true that selective serotonin uptake inhibitor (SSRI) medications, such as fluoxetine, work through the brain's serotonin pathways, this is just part of the story. Conventional anti-depressants that act on the serotonin networks are effective for less than half of depressed patients prescribed them.

"Nobody believes in single neurotransmitter hypotheses anymore," says Phil Cowen, Professor of Psychopharmacology at the University of Oxford. "One can't explain depression as one defect in any single neurotransmitter. They may be involved, but they are just part players in a complex system."

Prof. Cowen used magnetic resonance spectroscopy to measure levels of GABA, glutamate and glutathione in the brain, in a study published in the journal *Psychopharmacology* last year. Although depressed patients had lowered levels of glutathione in the cortex of the brain, this was only one small piece of the bigger picture.

Peeking under the hood

The greatest advance in explaining the neurological mechanisms at play in depression is the rise of brain imaging technologies. Analysing changes in blood flow, anatomy and electrical activity in the brains of depressed individuals has allowed scientists to discover measurable, quantifiable differences, such as a reduction in the size of the hippocampus – a region crucial in forming new memories.

But even when neuroscientists can find specific 'scar effects' in one part of the brain, this again is just part of the picture: no one brain region is at fault in depression.

"We increasingly see depression as a disturbance of neural circuitry, with the involvement of multiple neurotransmitters, neuromodulators and anatomical regions," says Prof. Cowen.

One popular model is that the limbic system – the so-called 'reptilian' brain, which includes regions such as the amygdala – is overactive, while the prefrontal cortex, which would normally regulate the activity of the limbic system, is underactive.

"The net result of having an overactive amount of fear coming up from the bottom of the brain, and not enough top down control of it, is that

Anti-depressants, such as fluoxetine, are effective for less than half of patients

GETTY IMAGES / ALAMY

Depression has a great deal to do with the ways that people perceive disappointments, not the nature of the experiences alone

you will look around the world and tend to see nasty things more than other people will," says Prof. Cowen.

Negative bias

In other words: depression has a great deal to do with the ways that people perceive disappointments and trauma, and not the nature of the experiences alone. This might sound simple, but take the fact that 65-70 per cent of people do not become depressed following a bereavement, a diagnosis of cancer or another significant form of trauma.

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"Many people with depression have what we call a 'negative bias' – they focus on the bad things in life," explains psychologist Professor Catherine Harmer of the University of Oxford.

This bias means that people in a depressive state are worse at recognising happy facial expressions, slower at categorising and remembering positive self-referential personality words, and worse at remembering positive life events. This creates a cyclical feedback loop that worsens the initial depression.

"Given the same life event or stressor as a non-depressed person, depressed people will take more negative things away from it, which can be a way of just maintaining the symptoms of depression," says Prof. Harmer. "Anti-depressants break the cycle by helping depressed patients to quickly see things in a more positive light, and over time this leads to a steady improvement."

Evidence of this can be found in her research, summarised in the journal *Philosophical Transactions B*, which shows that when healthy, non-depressed people are given anti-depressants, they are more likely to remember positive information, as well. This gives us the biological evidence we need to 'fill the gap' in understanding how treatments for depression actually work.

"Using brain imaging technologies we can now connect the underlying psychological processes that are maintaining somebody's depression with the actual mechanisms in the brain," says Prof. Harmer.

If the neurological and neuro- →

chemical signals of depression might seem dauntingly complex, the root causes are even more so. Depression comes in many different forms, due to a litany of factors. For example, some people may experience happy childhoods, yet be genetically predisposed to develop depression – say, due to a family history of bipolar disorder. At the other end of the spectrum will be individuals without any such biological predisposition, but who suffer terrible trauma and abuse in early life.

"Though these two groups might exhibit similar symptoms, the mechanisms that underlie those symptoms will be different, and require different treatments," says Prof. Harmer. "Taking a more nuanced approach will allow us to create more personalised medicines."

Ultimately, there is unlikely to be a 'silver bullet' for depression – recovery will involve a combination of drugs and lifestyle changes

Personalised medicine

You may have heard of this buzz phrase before. One of the hottest ideas in medicine at the moment is the belief that genetic screening will allow physicians to prescribe their patients with drugs that only they will respond to. Less than half of all depressed patients respond to conventional SSRIs on the first try, and as many as a third do not respond to any drugs on offer today. Not only do we need new drugs, we also need ways of knowing if they will work for an individual, lest they waste years taking drugs that do nothing.

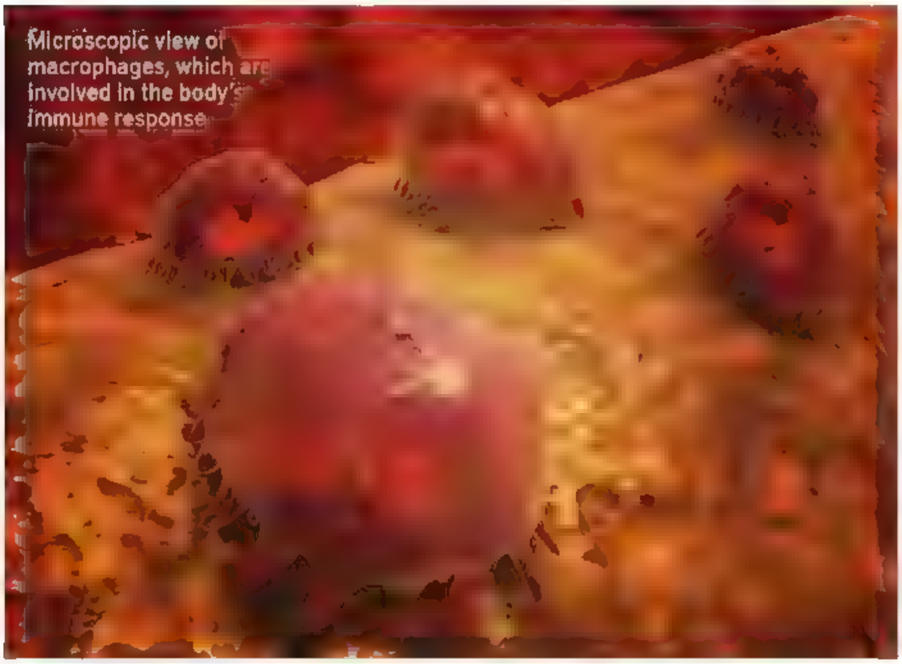
This spring the Royal College of Psychiatrists announced that they had formulated a blood test that would identify who would respond to conventional anti-depressants based on their blood levels of 'inflammation'. People with heightened inflammation, caused by molecules called cytokines, are less likely to respond to conventional anti-depressants, and about a third of people with depression have elevated levels of blood inflammation. This points to one of the most promising new avenues of research: the stress response, which could be a key factor for many forms of depression. In this new model, the feelings of malaise, low appetite and fatigue are just the byproducts of a body exhibiting a normal immune system response.

When we are infected or injured, white blood cells called macrophages produce cytokines, which signal to other macrophages to help fight the infection or repair the injury. Cytokines also head to the brain where they trigger 'neuro-inflammation', which brings about 'sickness behaviours', such as fatigue.

This makes evolutionary sense, because if you are ill it is best to convalesce and not to risk catching new infections. So white blood cells will also release cytokines when we are emotionally stressed, leading to the same feelings of fatigue and low mood. In the past this would be adaptive, but in today's environment, non-lethal threats, such as an empty bank account or angry boss, can trigger the same response.

In other words, the combination of our ancient biology – primed for fight or flight – with the stresses of modern life has produced an epidemic of malaise. In particular, people who experience abuse and trauma in childhood appear to have elevated baseline levels of inflammation – thus stressful experiences in adulthood tip them over the edge, resulting in depression.

People with high inflammation levels don't tend to respond to anti-depressants. But fortunately there are already drugs on the market that target the inflammatory response for other conditions, such as infliximab, normally used to treat



Microscopic view of macrophages, which are involved in the body's immune response

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Crohn's disease. Clinical trials with anti-inflammatories are already underway and show promise.

Other new drugs being explored include the psychedelic anaesthetic ketamine, which trials have shown to produce a rapid effect. But the relief from depression is short-lived, so researchers are hoping to identify the underlying neural mechanisms – which involve the NMDA receptors, and not the serotonin networks – to design new drugs that work through the same system. The psychedelic found in magic mushrooms – psilocybin – has also been shown to produce rapid, profound and long-lasting relief from depression.

"But the anti-inflammatory drugs are the most interesting options at the moment," says psychiatrist Professor Glyn Lewis, Chair in Clinical Trials and Applied Epidemiology at University College London.

The power of anti-inflammatories also explains why exercise has been shown to be helpful for people suffering from mild depression. But Prof. Lewis's research has found that people with severe cases of depression are unlikely to benefit from a simple jog around the park. "We concluded that advising people with depression to simply take more exercise would not be an effective intervention," he says. Stronger stuff is needed.

Mindfulness is the topic du jour in mental health circles. "Evidence shows that mindfulness can prevent relapses in people who are well, but were depressed in the past," says Prof. Lewis. "But there isn't much evidence it can treat depression on its own."

Ultimately, there is unlikely to be a 'silver bullet' cure for depression – recovery will involve a combination of the development of new drugs and lifestyle changes, such as avoiding stress, drinking and smoking, as well as eating better and exercising.

But Dr. Cowen says the best thing society could do is try to reduce the overwhelming prevalence of childhood trauma, which is one of the strongest predictors of developing depression in adulthood. "Giving more children the best experience possible growing up is one of the most powerful things we could do."

That, and to erase from mainstream media the idea that anti-depressants don't work, they lead to suicide, or that drug companies have simply pulled the wool over our eyes with misleading data.

"That is unhelpful for people who are depressed, it makes them feel what they're experiencing isn't serious, isn't real, and that they can be tricked out of it in some way," adds Dr. Cowen. "That, frankly, is insulting."

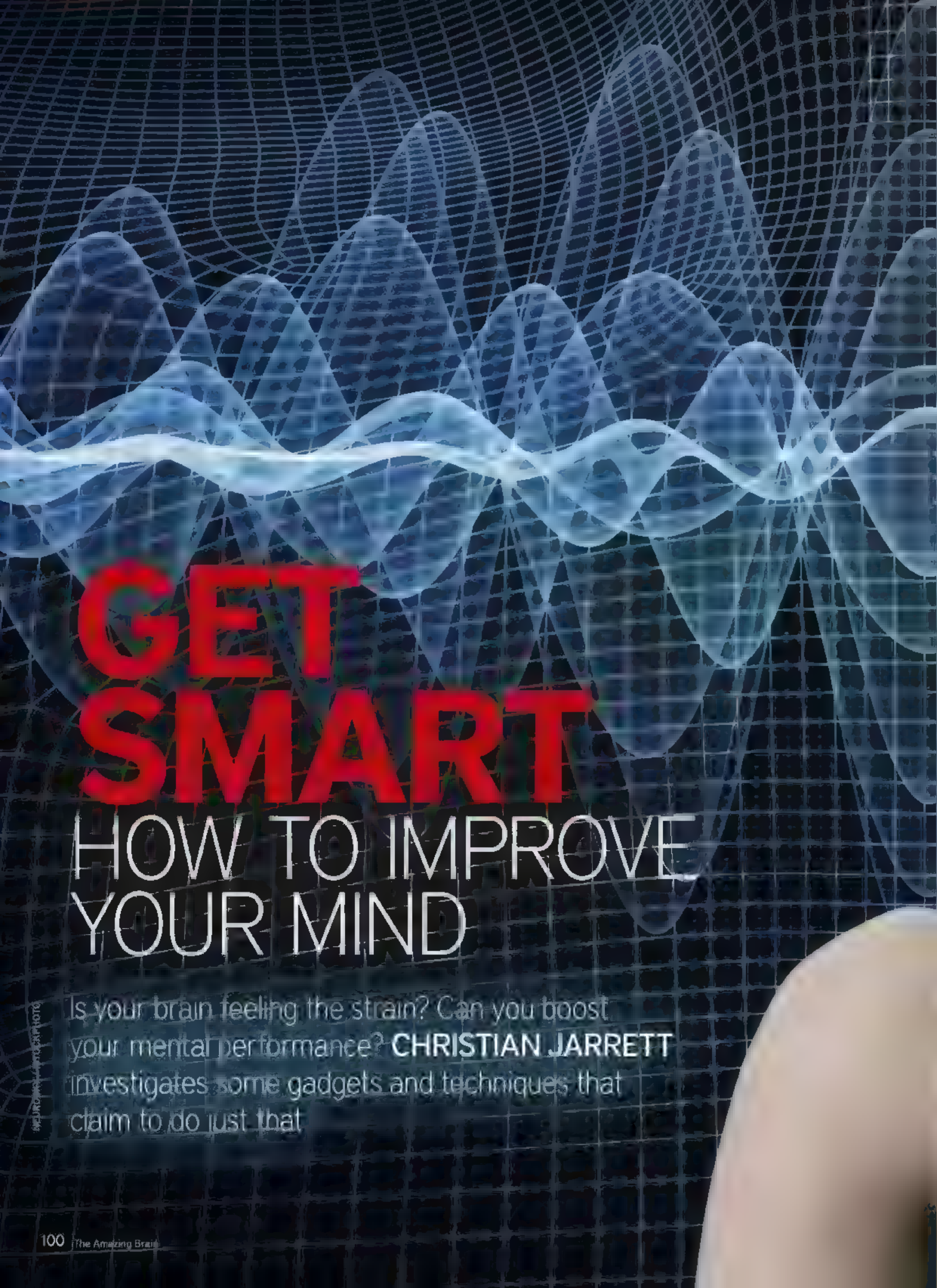
FUTURE

HOW THE BRAIN WILL EVOLVE IN YEARS TO COME

GET SMART
The science behind ways to improve your mind

HOW TO BUILD A BRAIN
The projects trying to create brains running on AI

MINDS



GET SMART

HOW TO IMPROVE YOUR MIND

Is your brain feeling the strain? Can you boost your mental performance? **CHRISTIAN JARRETT** investigates some gadgets and techniques that claim to do just that


A MindWave
Mobile Headset
from NeuroSky

> It is believed that tDCS alters the baseline levels of activity of neurons, so that they are more or less likely to fire

You're shopping on the main street. After passing the optician and the pharmacy, you reach the brain stimulation store with its headbands and skullcaps. They are designed to boost your mental performance or alter your mood by manipulating the activity of your brain.

Sounds far-fetched, doesn't it? In fact, the technology is already here and available to buy – but does it really work and is it safe?

An online company called foc.us offers a brain stimulation device, available from around $60, that promises to "overclock your brain" and "make your synapses fire faster". At a more experimental stage, there is the Halo headband. The San Francisco start-up company behind the Halo claims it will elevate your cognitive performance via so-called 'neuropriming'.

Meanwhile, the company NeuroSky offers MindWave mobile headsets (available from Amazon) and a PC game called Focus Pocus, which claims to "improve attention, concentration, information and retention ability".

How do they work?

The foc.us and Halo devices use weak electrical stimulation to either increase or decrease neuronal activity in the brain near where electrodes are placed on the head. This is known as transcranial direct current stimulation (tDCS).

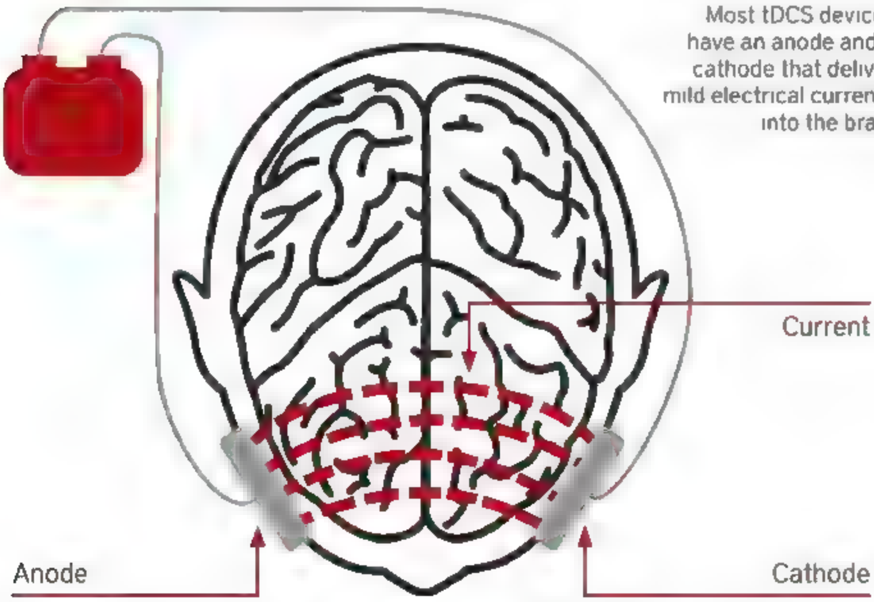
Mild electrical currents are delivered through the scalp and into the brain via electrodes – the anode and cathode. Applying stimulation through the anode is thought to increase the excitability of neurons, while cathodal stimulation has the opposite effect. It is believed that tDCS alters the baseline levels of activity of neurons, so that they are more or less likely to fire. It's also thought to change how neurons behave at synapses – the gaps over which neurons communicate with each other.

The claims made by the various companies touting these devices are rather vague. They refer to increasing your brain's plasticity and enhancing your mental performance. This may sound like nonsense, but there is peer-reviewed evidence suggesting that tDCS is associated with mental enhancements in healthy participants, the precise nature of which varies according to the site of stimulation.

Researchers have shown that zapping the brain with tDCS can improve memory, language learning, problem solving, visuo-spatial processing (such as the ability to detect targets on a computer screen) and even some social skills. Activities you do after brain stimulation – even going for a walk – can potentially reduce or reverse the effects. And, sceptics argue that few of these studies have controlled sufficiently for placebo effects.

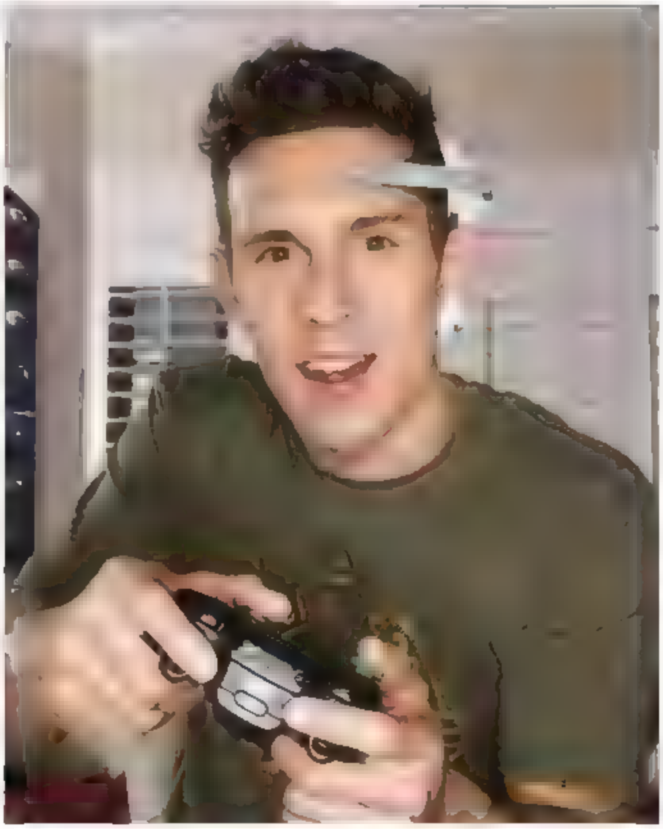
The NeuroSky headset and app are based on different technology. Devices like this record the waves of electrical activity that are emitted by your brain. They then feed this information back to you together with certain sounds and visuals. The idea is that you can then learn to control the frequency of your brain-waves, and in particular increase the amount of waves that you generate in the alpha range (8 to 12Hz).

NeuroSky claims that increasing your alpha brainwaves is associated with a range of cognitive benefits, especially enhanced short-term memory. But the evidence here is contentious. Many studies that are fully randomised and placebo- →



Most tDCS devices have an anode and a cathode that deliver mild electrical currents into the brain

ABOVE The SpringTMS system by eNeura claims to reduce migraine pain **BELOW LEFT** The foc.us brain stimulation device claims to make your synapses fire faster **BELOW RIGHT** Headsets have been developed by NeuroSky for gaming



ENEURA / FOCUS / NEUROSKY

Prof. Marom Bikson attaches a tDCS device to a colleague's head

DAN Z JOHNSON

controlled have failed to observe any benefits from alpha training.

Sceptics say using devices like this amounts to little more than a form of technology-assisted relaxation.

The only things at risk from the NeuroSky feedback device are likely to be your wallet and your schedule. Interestingly, the simple act of closing your eyes is known to increase brainwaves in the alpha range, so this is not a dangerous effect.

The situation with tDCS and devices like the foc.us headset is more complicated. While there have been no documented cases of serious adverse effects in over 100 studies, experts have issued a number of warnings about the possible risks of the technology. This includes the fact that the optimal dose of electricity is different from person to person. When using a device at home, there's no way for you to know how much power you'll need.

Even the amount of hair on your head can interfere with the dose. Another factor is that the long-term effects are unknown. Besides the risk of headaches or scalp burns, at least two studies have shown that by enhancing mental agility in one domain, you also impair performance in another.

Based on these uncertainties, experts have begun to ramp up their cautionary rhetoric. Dr. Nick Davis, a neuroscientist at Swansea University, published a paper arguing that tDCS shouldn't be referred to as a non-invasive technology. "Any technique which directly affects brain tissue to generate such powerful, acute and long-lasting effects should be treated with the same respect as any surgical technique," he and his colleagues wrote.

Others have likened the risks of tDCS to those associated with pharmaceutical drugs. "Meddling with the tDCS dose is potentially as dangerous as tampering with a drug's chemical composition," wrote Professor Marom Bikson at the City University of New York. Other concerns are more ethical and philosophical. By using a brain stimulation device to alter your social skills, are you changing your identity or personality? If we can use these gadgets to boost our mood at will, might we lose our drive to fight injustice? Could we become addicted?

Lastly, some have raised the spectre of unwanted brain stimulation. Choosing to enhance our brains with a headset is one thing, but what if such interventions were eventually imposed on criminals to correct their immorality, or made compulsory for pupils struggling at school?

Meddling with the tDCS dose is potentially as dangerous as tampering with a drug's chemical composition

Professor Marom Bikson, City University of New York

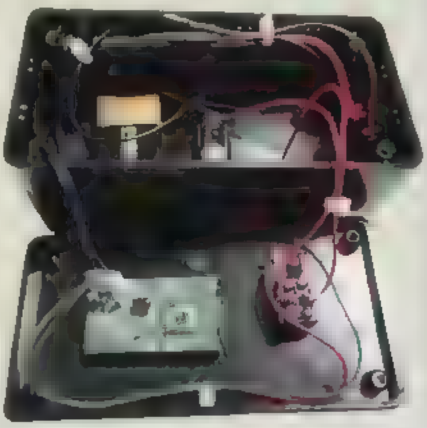
DIY brain stimulation

Some brain enthusiasts are taking matters into their own hands by making their own stimulation devices. But are they safe?

It's not that complicated to create your own tDCS device, and there are plenty of videos online to show you how it's done. Perhaps it's little wonder that a community of do-it-yourself brain-zapping enthusiasts has developed.

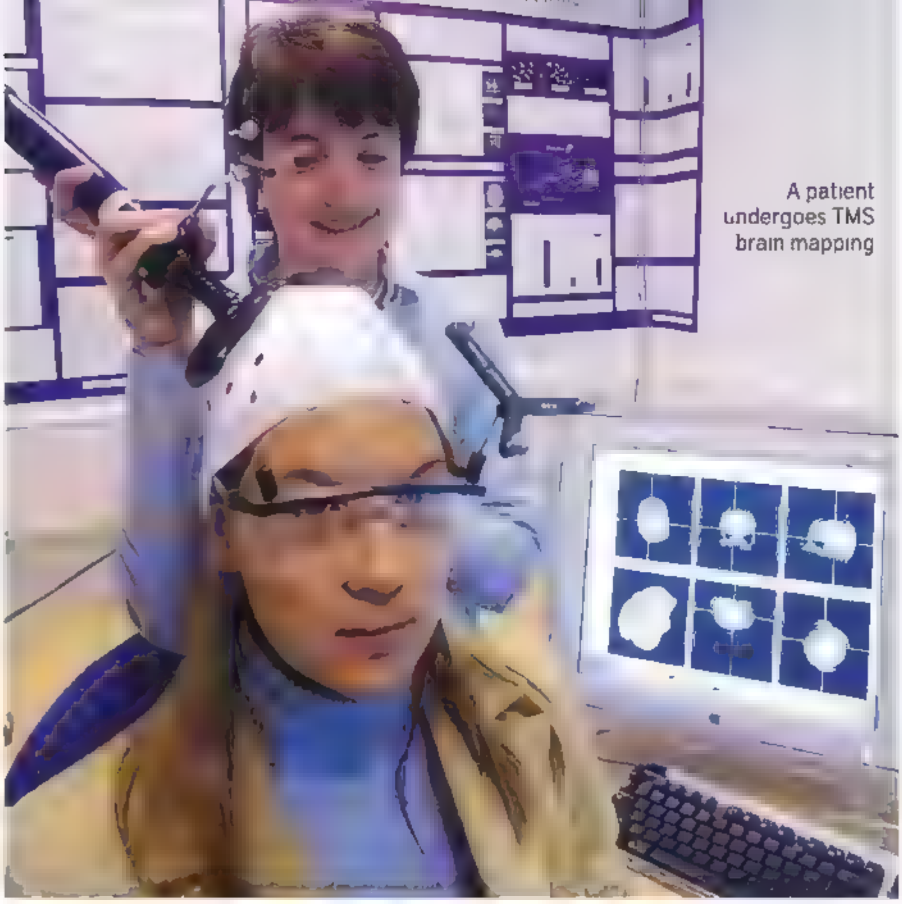
For example, there's an online subreddit of over 8,400 members who share tips and articles with each other about the technology. One article worries about foc.us, noting with alarm that they have been out of stock of headsets for some time

Part of the reason there is so much enthusiasm is that media reports are biased. After analysing press coverage of tDCS since 2006, a group of Canadian neuroscientists found that most reports focused on the benefits of brain stimulation without noting the potential drawbacks. The team called for more balanced reporting on brain stimulation. Indeed, experts warn that the science behind brain stimulation is stil immature, and the long-term effects of its use are still unknown.



Other technologies

Alpha-based neurofeedback and tDCS are not the only tricks in town when it comes to real-life thinking →



A patient undergoes TMS brain mapping

caps. Another technology that shows promise is known as transcranial magnetic stimulation (TMS), in which a magnetic field is used to alter neuronal function.

Although it's more expensive and less portable, TMS – like tDCS – has been reported to have a number of positive effects, especially as a potential treatment for depression and chronic pain. One study even claimed that TMS can unlock hidden savant-like skills in all of us, such as the ability to count a large array of objects in an instant.

But the evidence base is preliminary. UK health advisory body NICE says TMS may be used with normal arrangements for clinical governence and audit. In relation to pain management, it has approved TMS as a treatment for migraines, but recommends it is only provided by headache specialists. This has not stopped commercial handheld devices appearing on the market.

The SpringTMS system is produced by Californian company eNeura, and is touted as "the only non-drug therapy clinically proven to effectively stop or reduce migraine at the first sign of pain". It is revealing to note that the evidence for its effectiveness comes from only one small manufacturer-sponsored study and post-marketing surveys.

Finally, there is one other real-life thinking cap that deserves a mention. Although widely derided, neuroscientist Michael Persinger claims his God Helmet can help wearers achieve union with the Almighty. Like TMS, it delivers magnetic fields to the brain, but they are far weaker and of a different kind. In fact, psychologist Craig Aaen-Stockdale has pointed out that the magnet on your fridge is 5,000 times stronger than the God Helmet. Perhaps it's no surprise that a study by Swedish researchers found no evidence that a device similar to Persinger's invention was able to help wearers have any kind of enhanced religious experience. For his part, Persinger said the Swedish device obviously wasn't working properly.

Proceed with caution

Although the commercial release of brain stimulation devices is arguably a little premature, it's almost inevitable that their use is going to become more and more widespread.

Looking ahead, there are likely to be both clinical applications of these devices and lifestyle- or performance-enhancing products.

In a clinical context, researchers are busy conducting more robust, controlled trials to establish what kind of applications are genuinely effective, and how best to apply the technology safely. But, when it comes to brain stimulation in our everyday lives, the outlook is far more unpredictable. There will undoubtedly be a lot more commercial hype about the benefits of the technology, and it will be difficult to control how people choose to use it.

Whether used as a clinical tool or to boost healthy performance, it's worth remembering that the brain stimulation devices of today or tomorrow are unlikely to offer a quick fix. It's better to see these thinking caps as offering a technological tail wind, giving a boost to our own hard work, whether that be in the context of studying, sports practise or rehabilitation from illness. ■

> Any technique which directly affects brain tissue should be treated with the same respect as any surgical technique
>
> *Dr. Nick Davis, Swansea University*

Train your brain

Forget brain-training games and apps, cognitive psychologists and neuroscientists have other ideas for how to increase your IQ

It's well known that exercise can help you keep in shape, lose weight and tone up. But it's also been shown to protect us from forgetfulness, and improve thought processes and problem solving.

Just like your body requires a good workout, as you get older your brain needs help staying active. Regularly exercising your brain cells is key to keeping sharp. After all, as neurons can live for over 100 years, they need to be nurtured.

But, in the last decade or so, we've been inundated with adverts for brain-training games that claim to keep our little grey cells in prime condition. The big question is: do they work?

The verdict is still out Most evidence suggests that you only improve on the specific tasks in the games, rather than the benefits generalising to your all-round IQ. Because of this, a group of leading cognitive psychologists and neuroscientists say that claims brain-training games improve general cognitive abilities or help prevent dementia are "exaggerated and misleading".

So to maintain the neural connections in your brain – and make new ones – it's probably not worth spending a fortune on brain-training games and apps. Instead, experts suggest learning a language, doing crosswords, solving Sudoku puzzles – or kicking back with a session of World of Warcraft. That's right. Next time you get scolded for always playing video games, your comeback is that they have been shown to improve problem solving

It's not just brain stimulation gadgets and video games that have been linked with potential benefits for the brain. Research shows intriguing evidence that mindfulness meditation can change the physical structure of the brain, more than regular activities, specifically the rostrolateral prefrontal cortex (RLPFC) and dorsal anterior cingulate cortex (dACC), areas which are involved in thinking about ourselves and monitoring our own behaviour

Around a decade ago, neuroscientist Richard Davidson at the University of Wisconsin scanned the brains of Buddhist monks who practise mindfulness and found their brain activity patterns were significantly different from those of untrained students used as 'controls'. However, while meditation seems to affect brain structure and function, science has yet to find out whether these neural effects have any real-life benefits.

Mindfulness meditation has been found to change the structure of the brain

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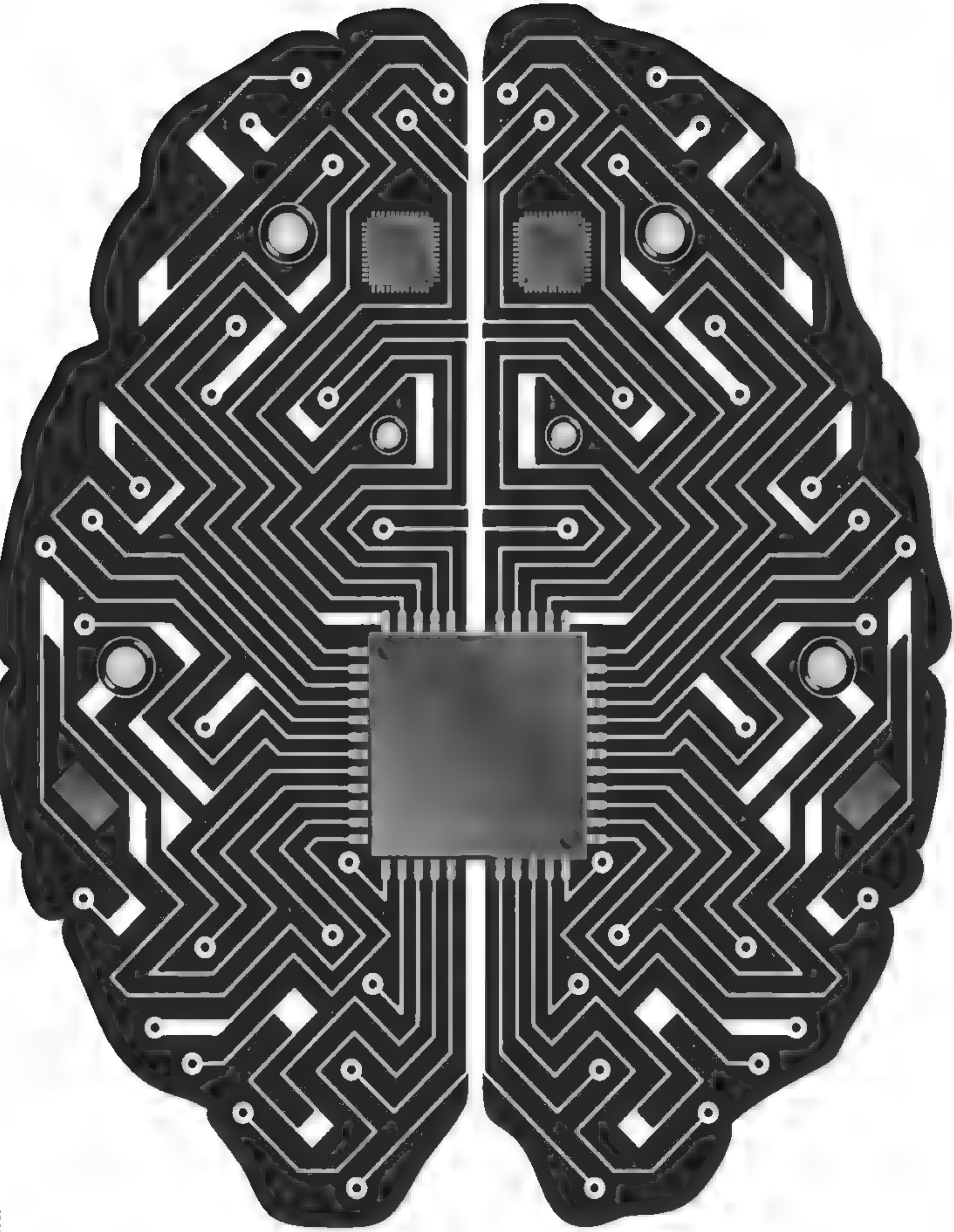
HOW TO BUILD A BRAIN

It's the question on everyone's lips – when will machines learn to truly think for themselves? **PETER J. BENTLEY** looks at the projects trying to create brains running on artificial intelligence



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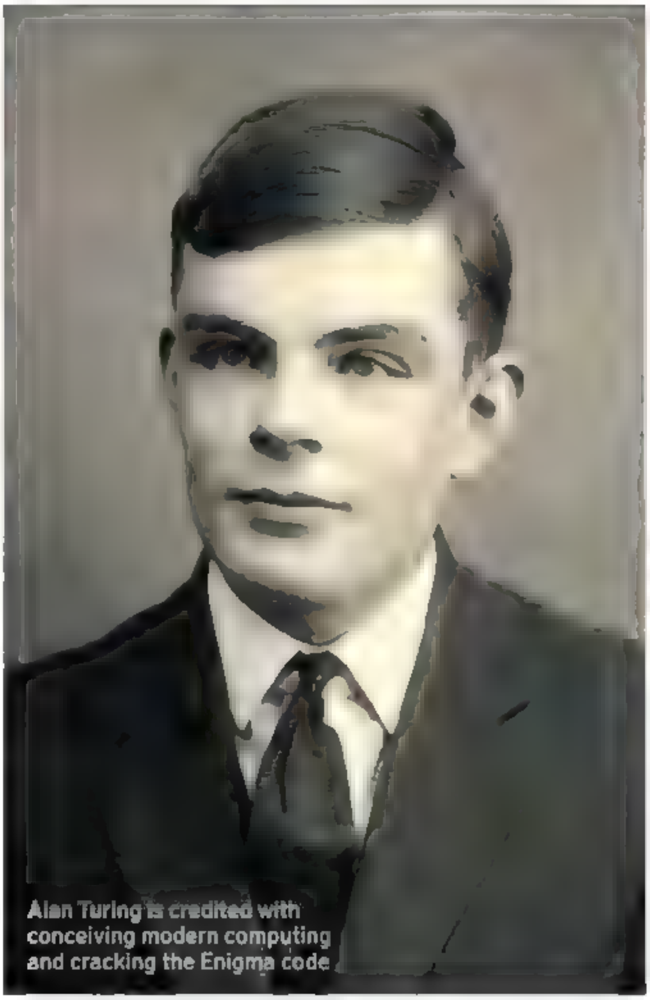


Alan Turing is credited with conceiving modern computing and cracking the Enigma code

Renowned code-breaker and mathematician Alan Turing famously said in 1950: "I believe that at the end of the century the use of words and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted."

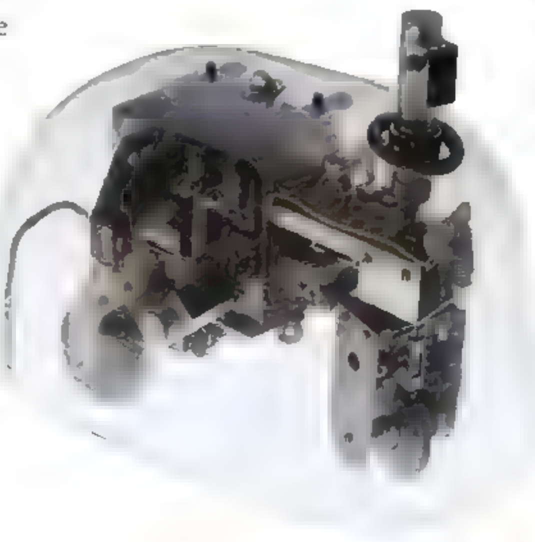
Turing was ahead of his time. But perhaps he was only a few decades out. Today, research groups and tech companies are actively pursuing the dream of making a brain inside a computer. Some try to understand how brains work and produce software components that might duplicate different brain functions – a module to understand text, another for planning, another for short term memory. Some try to exploit the vast data available and use statistics and powerful computers to infer knowledge. Some try to create detailed software models of millions of neurons and 'virtually' connect them in the same way that our own brains are comprised from billions of neurons. Are these machines thinking? It would have been fascinating to ask Turing and see what he thought.

Birth of the artificial brain

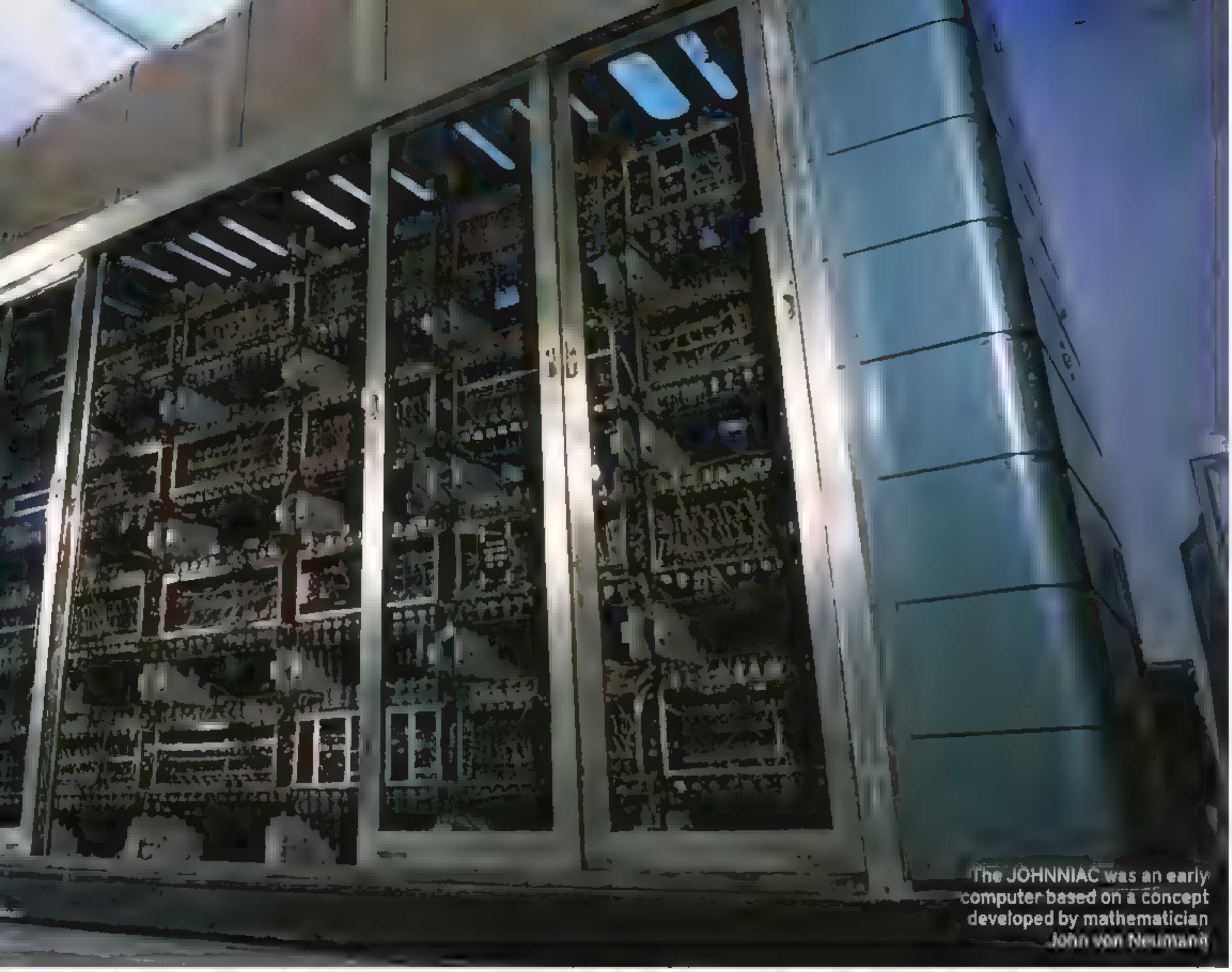
The pursuit of artificial intelligence is not new. Even before we created the first programmable computers, we were imagining that one day we might build an artificial mind. Neurophysiologist William Grey Walter was one of the earliest to have this idea. In the 1940s, he pioneered brain scanning technologies for medical use, and he also built several robot 'tortoises' that could follow a light and back away from obstacles. Just like biologists study animals to show that even a small number of electronic brain cells could exhibit complex behaviours, Walters studied these robot creatures.

As the first programmable computers were being designed in the late 1940s, engineers naturally compared their digital devices to brains. The very first easy-to-read description of how to build a programmable computer was written by a mathematician called John von Neumann. Amazingly, he frequently refers to the human brain in his report. He talks about "organs" in the computer, and how they would perform functions similar to "neurons in the human nervous system". He even tries to explain each major part of the computer in terms of the different kinds of neurons that had been discovered at the time. The von Neumann architecture became the blueprint for almost every computer built since then. We're all using artificial brains, every day.

As the years progressed and we tried to write software that made our computers behave in more 'brain-like' ways, we soon realised



A robot 'tortoise' designed by neurophysiologist Grey Walters in the 1940s



The JOHNNIAC was an early computer based on a concept developed by mathematician John von Neumann

that biological brains are incredibly intricate. Our computers were built as automatic calculating machines, and because of this they can do maths extremely quickly – much faster than us. But our brains are parallel 'understanding machines' that make sense of vast amounts of dubious information at the same time in order to discover useful new information and relationships about the things around us. Conventional computers are extremely bad at that kind of thing – when the numbers are a little bit wrong or incomplete, their answers are very wrong. We are quite capable of holding a conversation with someone in a crowded room and picking out their replies amongst a hundred other voices nearby. All a computer hears is noise. Our brains can happily enable us to control thousands of muscles as we run across rough ground, hum a tune and think about a difficult problem at the same time. Our computers struggle to do any one of these competently. Despite the amazing things we see in science fiction movies and the predictions we hear about, we still cannot make very clever artificial brains.

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The challenges

Today, we are in the strange situation that we can make robot dogs that run, robot snakes that slither, robot birds that fly – and even robot people (that look a little creepy). But they are all stupid. None have much more intelligence than a fruit fly – and most have considerably less.

This is why we still do not have (reliable) robot assistants that wash our windows or fight fires. The real world is a complicated place. Even the technological marvel of this decade, the self-driving car, is not truly intelligent. It combines radar sensing of its vicinity with detailed maps and GPS to figure out where it is and what to avoid. If the map is wrong or the radar sensor is disrupted by bad weather, the only thing the car knows to do is stop. Even a bee with its microscopic brain can navigate around its world better than our →

self-driving vehicles, and the bee has no roads to follow, and no maps to check its position.

Making a computer brain has turned out to be a tremendous challenge. The problem is that there are just so many unknowns. "Think of something like a novel or a movie," says Professor Peter Dayan, Director of the Gatsby Computational Neuroscience Unit at University College London. "We do not know how structured information about complex entities like these are represented in the activity of neurons. On a completely different scale, we also do not know the nature of bottom-up and top-down interactions in the cortex. But every scale has its own fascinating unsolved problems!"

A demonstration of how a Google self-driving car could help the elderly and partially sighted

Clever hardware

The state of the art in artificial brains uses very complicated software and specialised custom-designed computers to try and duplicate the workings of biological neurons. One pioneer in this area is Professor Steve Furber, from the University of Manchester, and originally the principal designer of the BBC Micro and the ARM microprocessor (the computer chip used in millions of mobile phones around the world).

For more than a decade, Prof. Furber has devoted his considerable energies into the creation of SpiNNaker – a special computer that will be made from a million processors working together, in order to simulate a billion neurons – that's one per cent of the neurons in the human brain. In the last two years, the SpinNNaker project has joined forces with the €1bn EU Flagship project known as the Human Brain Project. Progress is good, according to Prof. Furber. "As from 1st April we have an operational machine with 500,000 ARM cores," he says. "By the end of 2016 we should have around 800,000 cores. We will continue to expand this over the coming months towards the ultimate goal of a million cores. With 500,000 cores we can model up to 125 million neurons; with 800,000 cores 200 million neurons." With a few clever software upgrades, these numbers should improve still further.

SpiNNaker, and other novel computer architectures like it, are being developed to be research platforms, enabling researchers to understand how brains work. Like engineers testing models of aircraft in a wind tunnel, these scientists develop smaller models of brains inside these novel computers in order to understand better how brains work. "The main advantage of the large-scale [SpiNNaker computing] is the ability to explore the behaviour of neural networks without running into computational constraints or very long run-times," says Prof. Furber. "I see the platform being used for a range of different purposes, for example, large-scale biologically-informed models, such as point-neuron approximations to whole mouse-brain models and cortical

> I'd be surprised if we couldn't engineer most aspects of human-level artificial intelligence within 20 years or so
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> *Prof. Peter Dayan, University College London*

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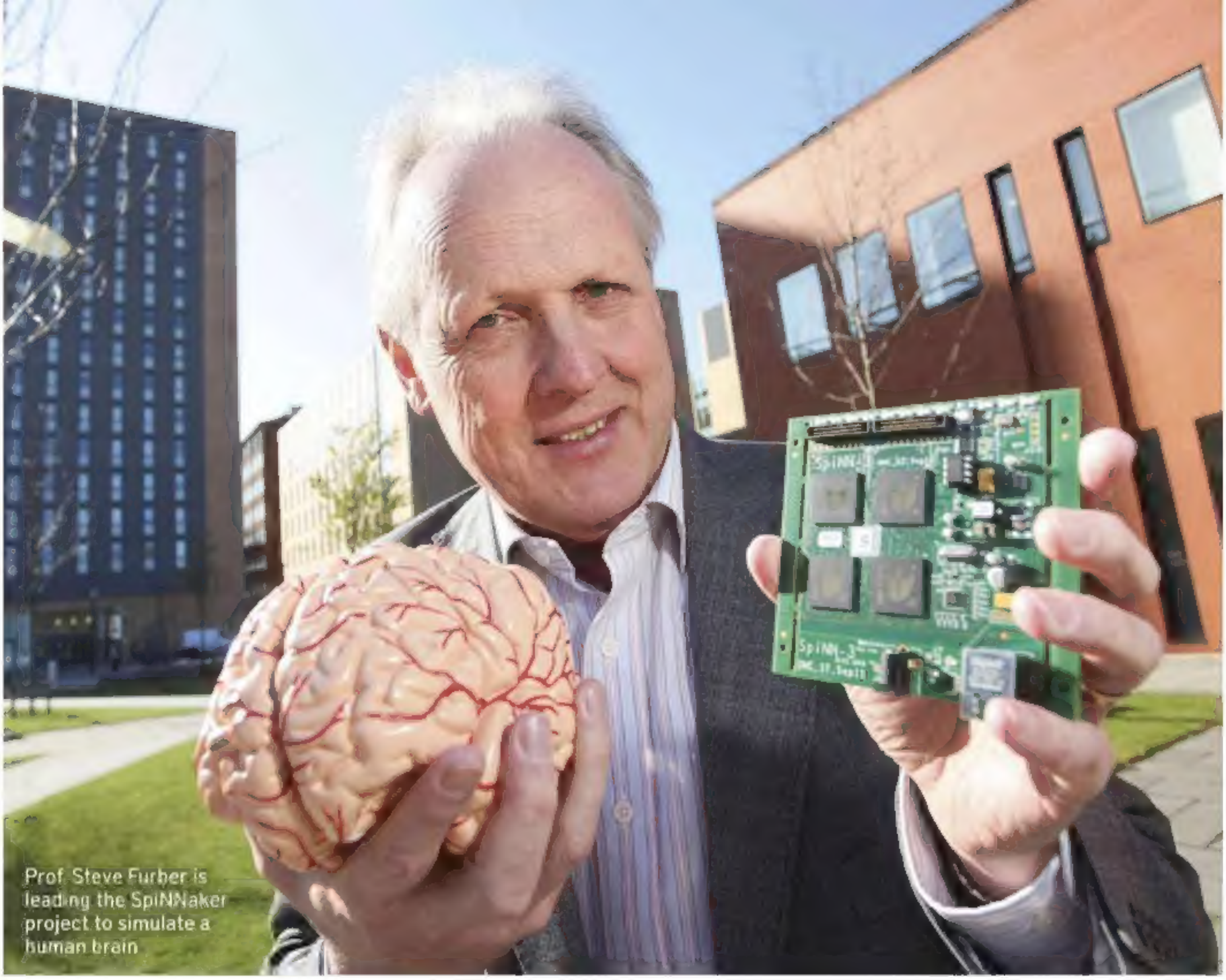

Prof. Steve Furber is leading the SpiNNaker project to simulate a human brain

UNIVERSITY OF MANCHESTER

surface models, and spiking Deep Networks for energy-efficient machine learning applications."

Artificial neural networks

While we may struggle to understand how brains really work, there has been considerable progress made in the use of much simpler models of the brain. Artificial neural networks, and their fashionable variety known as Deep Learning, are the latest big thing in Artificial Intelligence.

The first models of neural networks were created by the early pioneers in AI in the 1940s, using electronic circuits. Soon the first programs were created to model the idea that when two neurons fire together, the connection between them is enhanced. The artificial neural network fell out of fashion for some years until new kinds of networks were invented in the 1980s.

Suddenly there were new ways of connecting these artificial neurons. By giving them lots of data and adjusting their connections it became possible to train them to distinguish between different kinds of input. They could classify objects or cluster data into different groups, and even make predictions about what the next numbers in a sequence might be. These brain-like computer programs were now enabling computers to check for faults in factory production lines, understand handwriting or predict prices in the stock market.

Then, in 2006, a new breakthrough happened. Researchers discovered how to organise the networks in 'deep layers' – rows of neurons, connected to more rows, connected to more rows, and so on. When combined with serious computing power and large amounts of data to train the networks, researchers were suddenly able to create artificial brains that could learn far more complex tasks. The Deep Learning neural networks could now recognise features in images, understand speech, and even learn how to play simple computer games, or board games such as 'Go'.

The success of this approach has caused a flurry of activity in Deep Learning, and a new crop of AI companies have emerged that all claim to use the approach.

The success of current methods makes Prof. Dayan optimistic about the future of AI. "I'd be surprised if we couldn't engineer most aspects of human-level AI (not super-AI, though) within 20 years or so," he predicts. "However, this will not look like a 'faithful' model of the brain."

So how will we make an artificial brain? It is clear that we need faster computers, and new kinds of computer such as SpiNNaker. We also need to understand how real brains work in far greater detail – why neurons are connected together in very specific networks, and how those connections somehow enable our →

thoughts to circulate. It is likely that it will take decades of neuroscience research before we can discover some of the secrets hidden inside our skulls. This need for better knowledge has been recognised by the Brain Initiative – a massive American research programme announced by President Obama in 2013, dedicated to neuroscience, computer modelling and medicine relating to the brain.

Software, such as Siri, mimics human intelligence and natural conversation

Keeping it simple

There might be faster ways to make an artificial brain, though – perhaps using highly simplified models of neurons, such as those used in Deep Learning, or by getting our most powerful computers learning at the same time. We're starting to become better at handling these large neural networks, and we're discovering that different kinds are good at different kinds of learning.

Some researchers try to let the brains design themselves by adding evolution into the mix. After all, our own brains evolved because millions of years of challenges helped prune out all the less adaptive, less intelligent brain designs. Using special programs called genetic algorithms, computer scientists are able to evolve neural networks in the same way. There have been some remarkable successes, with 'virtual creatures' evolved to swim or run in their virtual worlds, and robot brains evolved to help them navigate the real world. But add evolution into the mix and suddenly you have to multiply the computation power by thousands or millions, so this approach may need another decade or two before our computers can cope.

Copy cats

The only other approach is to abandon the idea of neurons altogether and try to create software that simply duplicates the functionality of brains. Memory chips store memories better than brains – why not use them? It's been a favourite approach for many computer scientists and engineers over the decades, and most practical AIs (such as Apple's Siri and IBM's Watson) are combining several methods in exactly this way.

What is the right approach to make an artificial brain? It probably depends on what you want it to do.

But right now the biggest challenges remain unsolved. "They are conceptual rather than technical," says Professor Owen Holland, a pioneer of AI. "We don't really know yet what to do, and so the attention being given to how to do it may be misplaced. Trying to understand and model brains from the neuron up is probably a blind alley given the current state of knowledge, but I'd be very happy to be proved wrong."

And, in several decades, if our artificial brains are starting to reach the complexity of human brains, what then? Will they start to think for themselves as Alan Turing predicted in 1950?

"[Machine consciousness] will happen, and in decades rather than centuries," says Prof. Holland. "And instead of thinking about the social consequences of sharing the planet with millions of conscious robots, we should give some thought to the likely consequences of the demonstration that the apparent puzzle and miracle of consciousness is just a natural consequence of a particular arrangement of physical components. How important and precious will our consciousness seem once the mystery is history?" ■

> Machine consciousness will happen, and in decades rather than centuries. We should think about the likely consequences
>
> *Prof. Owen Holland, University of Sussex*

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BBC FOCUS MAGAZINE

THE AMAZING BRAIN

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Prof. Ian Robertson is the author of *The Winner Effect: How Power Affects Your Brain*. On page 52 he reveals why power corrupts.